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Yield Variations With Special Reference to Border Effects in Field Tests

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FOR REVIEWING

By R. J. Borden

Largely due to observations made during the early growth of sugar cane upon the outer rows of adjacent, differently treated plots in field tests, opinions have differed concerning the extent of the influence on final yields which could be due to border effect. Hence from two recently harvested nitrogen tests at Waipio, evidence was sought to prove the existence of such effects. The results lead us to the following conclusions: (a) When the plan of the experiment is such that the treatment differentials for adjacent plots are apt to cause large differences in final yields, a rather definite border effect will be found, but (b) when the treatments on adjacent plots are not greatly different and the expected yield differences are apt to be quite small, then little or no border effect can be expected.

It is not an uncommon occurrence, when making observations of the growth of sugar cane during its early development while the stalks are still erect, to find a lack of uniformity and to see some rather definite growth differences. Unfortunately we have little proof of what actually happens to these early growth differences after the cane goes down and so we do not know whether or not they are carried right through to harvest and actually affect the final yields. Similarly and perhaps just as often, our observations reveal a remarkable degree of growth uniformity during these first 6 or 8 months of development but results at harvest indicate that this early uniformity is not always carried through the crop. Thus it is quite apparent that different sorts of growth influences become operative during the second half of the growth period which greatly modify the cane growth made earlier.

There is some evidence from field tests that early visual differences in growth may not have as great an influence on final yields as we are sometimes inclined to imagine. For instance, on most of our older cane lands when phosphate fertilizers are now supplied for a sugar cane crop at time of planting, a pronounced increase is generally seen over the check plots in the early growth and tillering, and obser-

vations of this initial stimulus frequently give rise to unduly optimistic estimates of final cane yields. However, as the crop develops, the growth differences between the phosphate-fertilized cane and the cane which has received no phosphate are found to gradually even up, and when the crop is finally harvested no significant differences in yield are found. In contrast, we have such observations as were made in Waipio Experiment 110 where there were no observable differences in cane growth for the first 5½ months between the "no-nitrogen" and "nitrogen-treated" plots, and yet at harvest 15 months later a very substantial difference in cane yield favored the latter.

The observation of early growth differences in adjacent but differently treated plots in field tests has sometimes led to an unwarranted interpretation, and has even cast some doubt on the validity of final yield figures submitted after harvest. Our initially formed opinion is apt to be biased by what we see early, and because we do not see the changes which take place later, our first judgment persists. It is our opinion that our observations cannot be depended upon to show a high correlation with final yields, because growth influences, the effects of which are not easily recognized after the cane is recumbent, can cause great changes in factors which contribute to final cane yields.

If the preceding comments concerning early observations of cane growth are admitted, then it is easy to agree that "border effect" has been seen in some of our field experiments. But before we are willing to admit that such observed "border effect" has greatly influenced yield comparisons and led to a faulty interpretation of the results, we shall need better proof.

We shall define "border effect" in field tests as that difference in cane yield which results when one (or more) of the outside or border rows in a plot receives an advantage or a disadvantage in some growth factor which is not received by an inside row. Such factors as differences in nutrients, water, sunlight, and exposure to wind are apt to be these chief causes.

Since nitrogen tests are so important in our plan of research, we have sought our evidence from 2 nitrogen tests recently conducted at Waipio. In Experiment No. 110, a heavy nitrogen application (220 pounds per acre) was compared with no nitrogen in several groups of adjacent plots. This is probably a larger nitrogen differential than we would commonly use in an "amounts-of-nitrogen" experiment but it was planned this way in order to get a better idea of the maximum extent of any border effect which might be found.

Observations made at 3½ months showed no evidence of a difference in growth between the two treatments and not until 5½ months was it possible to distinguish any differences, and then it was chiefly a leaf-color difference which distinguished the treatments. Furthermore it is very doubtful that a border effect was actually observed while this cane was still erect.

When it was time to harvest the crop adequate supervision* was supplied to see that the cane was cut and weighed separately from each row in each plot. Since the rows were of variable length all row yields were subsequently calculated to a tons-per-acre basis and our studies have been made from these T.C.A. figures.

The yields of the individual rows which were harvested are graphically shown in Fig. 1. This test occupied 5 blocks (of 2 plots per block) in 4 separated areas

* By Messrs. Smith, Yamasaki, Ching, and McCall.

Waipio Expt. 110 AN - Variations in Yields of Adjacent Rows

Yields from Each Row as TCA

LEGEND:

●————————● D PLOTS @. 220 LBS. N/ACRE
○--------○ X PLOTS, – NO NITROGEN

TCA

200

BLOCKS 1 AND 2 - FOUR 8-ROW PLOTS

150

ONE UNPLANTED ROW

ONE UNPLANTED ROW

100

50   Plot 55 X | | Plot 56 D | | Plot 57 X | | Plot 58 D
      1 2 3 4 5 6 7 8 1 2 3 4 5 6 7 8 1 2 3 4 5 6 7 8 1 2 3 4 5 6 7 8
                          ROW NUMBERS

TCA

200

BLOCK 3 - TWO 9-ROW PLOTS

150

ONE ROW @ 220 LBS. N

ONE ROW WITHOUT N

100

50   Plot 25 D | | Plot 26 X
      1 2 3 4 5 6 7 8 9 1 2 3 4 5 6 7 8 9
              ROW NUMBERS

TCA

200   200

BLOCK 4 - TWO 6-ROW PLOTS   BLOCK 5 - TWO 6-ROW PLOTS

150   150

ONE ROW @ 220 LBS. N   ONE ROW WITHOUT N

ONE ROW @ 220 LBS. N   ONE ROW @ 220 LBS. N

100   100

50   Plot 9D | |Plot 10X   50   Plot 31 X | | Plot 32 D
      1 2 3 4 5 6 1 2 3 4 5 6   1 2 3 4 5 6 1 2 3 4 5 6
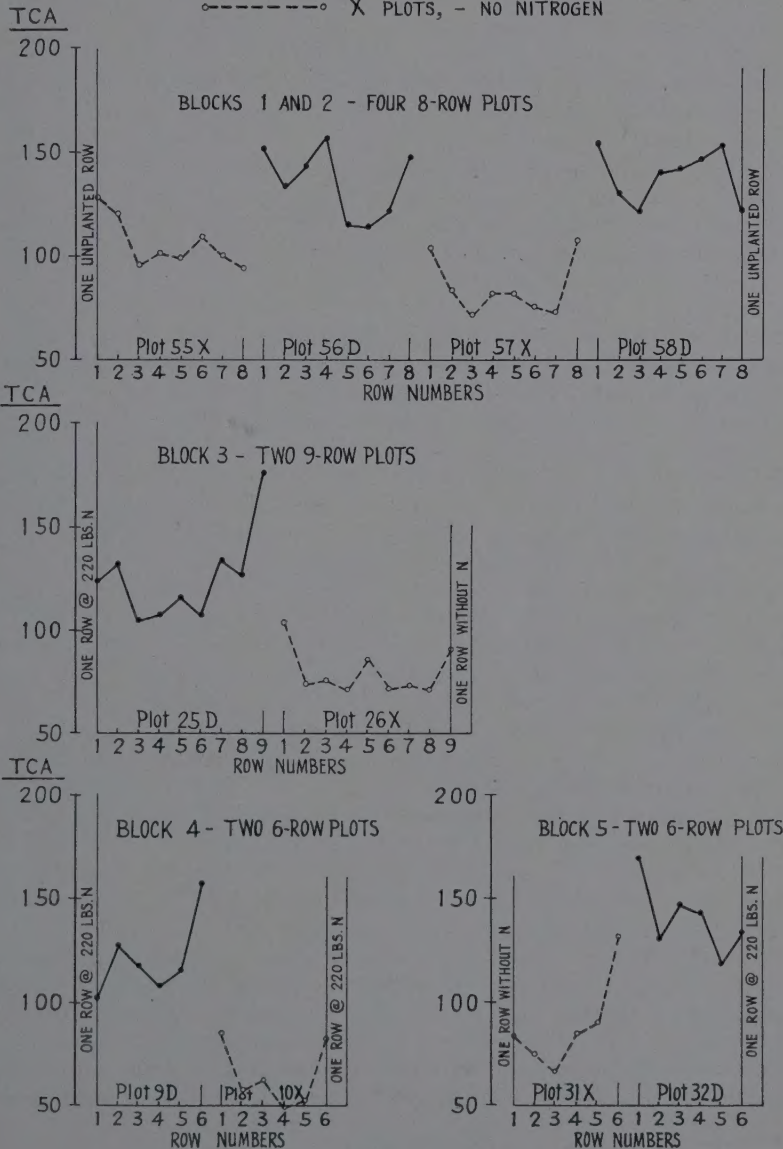   ROW NUMBERS   ROW NUMBERS

Fig. 1

in Field L.   In blocks 1 and 2 there were 8 rows in each plot; block 3 had two 9-row plots, and plots in blocks 4 and 5 had only 6 rows each.

An inspection of Fig. 1 shows some rather clear-cut evidence of border effect as judged by the actual cane yields harvested and, as will be seen shortly, a statistical analysis of the yields from the border rows tends to confirm this evidence.   Except for row 8 in plot 55 X, the border rows in the other plots with Treatment X (no nitrogen) appear to have been increased through their intimate association with cane in an adjacent row which had received nitrogen fertilizer; we assume that they "stole" some of the nitrogen.   At the same time border rows in the "D" plots which received nitrogen also seem to have benefited by being next to cane which received none; apparently they were not adversely affected by their loss of nitrogen to their adjacent "no-nitrogen" cane and were benefited by the extra sunlight made available when growth of the stalks in the adjacent "no-nitrogen" row failed to keep up with them.

To support the evidence in Fig. 1 we have the following statistical analysis.   We have made use of the yields from all rows except the border rows to determine the extent of the expected or chance variation which is probably not a border effect within this test area.   Thus we find that after deducting the treatment effects and the block effects from the total variation for the 54 inside rows in this test, we have a standard deviation of 12.4 tons.   With this figure for the chance error of a single row as our guide, we can assume that the individual row error which falls within an amount of "t"* times this standard deviation is quite likely an expected error for this area or population of cane, and therefore cannot be safely attributed to any specific border effect.   If, however, the individual error for a border row is greater than the expected error (24.9 tons in this case), we are probably right in assuming that it has been influenced by some factor other than chance, and so we can more safely assume that a definite border effect has been measured.

To find the amount of individual error in the yield from each of the border rows, we first assessed the difference between each border row yield and the general mean yield of all 54 inside rows, and from this difference we then substracted the variation due in each case to the specific treatment of the border row and also to that variation which is most likely due to its position in a specific block.   This was done by use of the following formula:†

$\Sigma e = \Sigma [(x - x) - (x_t - x) - (x_b - x)]$; which when simplified becomes $e = x - x_t - x_b + x$, where e = individual row error; x = yield of border row; x = mean yield from inside rows; x_t = treatment average; and x_b = block average.

This calculation and its results are shown in Table I, being broken down into 6 groupings to allow for slight differences in their border row exposures.   They may be discussed as follows:

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* t for P @ .05.

† For proof of identity, W. H. Beckett in Vol. IX, pp. 10 of "Tropical Agriculture," 1932, refers to Journ. Royal Stat. Soc. XCIV, Part II, "Mathematical theorem involved in the analysis of variance."

TABLE I

ERRORS IN BORDER ROWS (EXPERIMENT 110)

$$\Sigma e = \Sigma \left[(x - x) - (x_t - x) - (x_b - x) \right]$$

GROUP I	Plot	Rows	Row yield(x)	General mean(x)	Treatment mean(x_t)	Block mean(x_b)	e
	55	8	94	104	79	118	+ 1
	57	1	104	104	79	108	+21
Rows with no nitrogen adjacent to rows with high nitrogen	57	8	108	104	79	108	+25*
	26	1	103	104	79	96	+32*
	10	1	85	104	79	86	+24
	10	6	81	104	79	86	+20
	31	6	131	104	79	107	+49*
GROUP II							
	56	1	151	104	128	118	+ 9
Rows with high nitrogen adjacent to rows with no nitrogen	56	8	148	104	128	118	+ 6
	58	1	154	104	128	108	+22
	25	9	176	104	128	96	+56*
	9	6	157	104	128	86	+47*
	32	1	169	104	128	107	+38*
GROUP III							
	25	1	124	104	128	96	+ 4
High N adjacent to high N	9	1	103	104	128	86	− 7
	32	6	133	104	128	107	+ 2
GROUP IV							
No N adjacent to no N	26	9	89	104	79	96	+18
	31	1	83	104	79	107	+ 1
GROUP V							
High N adjacent to unplanted row	58	8	121	104	128	108	−11
GROUP VI							
No N adjacent to unplanted row	55	1	129	104	79	118	+36*

Expected e = 2.01 × 12.4 = 24.9 tons.   * = significant.

The 7 border rows in Group I, none of which had received any nitrogen fertilizer but were adjacent to cane rows which had been heavily fertilized with nitrogen, all had positive amounts of error which in three cases were greater than would normally be expected by chance; hence this would appear as fairly reliable confirmation of a border effect on cane in these nitrogen-deficient border rows.

Three of the 6 rows in Group II, rows which had been fertilized with nitrogen and which adjoined non-fertilized rows, had errors which were in excess of the expected chance error; hence this fact also supports other evidence of border effect on the high-nitrogen-fertilized rows.

In Groups III and IV there is no statistical proof of border effect and this is to be expected since the border rows are adjacent to rows of cane which had been similarly fertilized.

Data in Groups V and VI are too scanty for discussion but it would certainly appear that row 1 in plot 55 derived some benefit from having the unplanted row adjacent.

200

TCA

WAIPIO   EXPT. 114·AN

VARIATIONS IN YIELDS OF
ADJACENT ROWS

TCA YIELDS FROM EACH ROW IN
16 PLOTS OF 6 ROWS PER PLOT, –
SHOWING RESPECTIVE POSITIONS
ON FIELD LAYOUT:

H PLOTS = N @ 200 LBS./AC., ●————
L ,,   = N @ 120 ,, ,, , ○————○

(ALL ROWS OF CROP CANE RECEIVED
SAME AMOUNT OF NITROGEN
AS ADJACENT ROW IN TEST AREA)

200
150
100
Plot 45 H | | Plot 46 L

200
150
100
Plot 47 L | | Plot 48 H | | Plot 49 L | | Plot 50 H

220
200
150
100
Plot 51 H | | Plot 52 L | | Plot 53 H | | Plot 54 L

220
200
150
100
Plot 55 L | | Plot 56 H

1 2 3 4 5 6 1 2 3 4 5 6 1 2 3 4 5 6 1 2 3 4 5 6
ADJACENT ROW NUMBERS

TCA
220
200
150
100
Plot 41 H | | Plot 42 L

220
200
150
100
Plot 43 L | | Plot 44 H
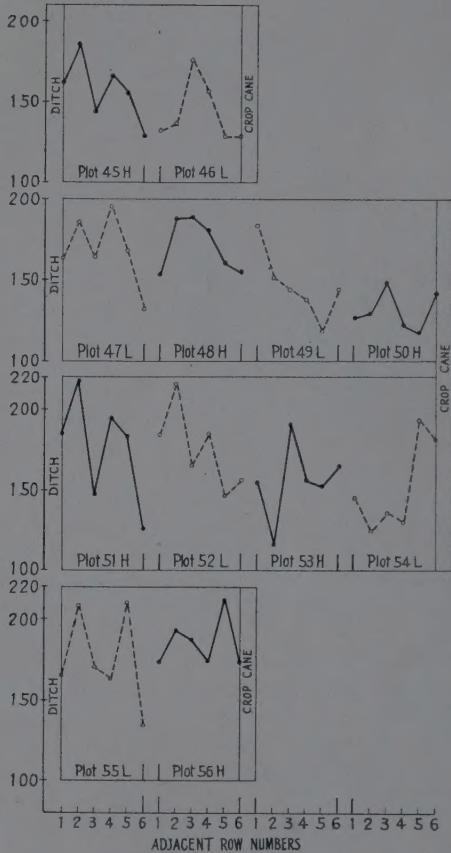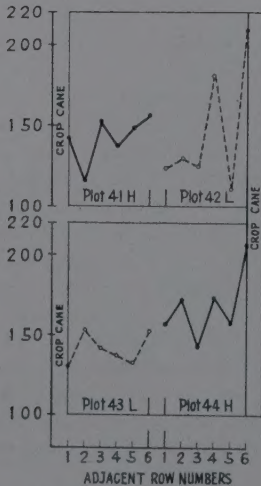
1 2 3 4 5 6 1 2 3 4 5 6
ADJACENT ROW NUMBERS

Fig. 2

Our second study was made on cane cut from Waipio Experiment 114. This test was located on a very uniform piece of land in Field 21. Sixteen 6-row plots were carefully planted with 32–8560 cane on August 4, and thereafter handled to assure as uniform growth as possible. Two nitrogen differentials were used, according to the following plan of fertilization:

Plots	Sept. 24	Nov. 22	March 23	Total
	Pounds per acre			
L	40	40	40	120
H	40	80	80	200

At no time during the growth of this crop were growth differences observed although the general color of the "H" plots may have been a slightly darker green during the first summer; however, this color difference was never clearly apparent in the border rows of adjacent plots.

At harvest* the rows in this test were cut separately and all cane weighed in the field. From these weights, Fig. 2 has been prepared with all cane weights calculated to their equivalent T.C.A. (net area basis). This graph vividly shows the possible nature and extent of the yield variation which may be found in adjacent single rows of 32–8560 plant cane, which in its early growth stages was remarkably uniform and certainly showed no evidence to indicate such extremes of variation as were actually measured when harvested at 22 months. Such facts as these should make quite clear what we have repeatedly emphasized—that yields from single rows of cane are wholly unreliable for comparative purposes because they are the result of so many unknown influences.

Careful study of Fig. 2 will show that the T.C.A. differences between the border row (No. 1 or No. 6) and the adjacent or next inside row (No. 2 or No. 5) in these plots are perhaps no more variable than the differences between some of the inside adjacent rows which are positionally removed from border effect. This makes it difficult to support any great probability that border effect has been a factor in this test. Perhaps the nature of the plan of fertilization was not conducive to border effect for unlike the large differentials in the nitrogen fertilization of Experiment 110 which we have already discussed, the treatment differences in this Experiment 114 were quite small; here it was not a case of "with or without" nitrogen but rather a case of "some and more" and apparently "some" was enough, for we found no real gain for "more" nitrogen (Treatment H) when the test was finally harvested.

A statistical study of these row yields made as previously described for Experiment 110, gives us a high figure of 20.7 tons for the standard deviation of the 64 inside cane rows in this area and indicates that in this 160-ton cane an individual row error of 41.6 tons could be expected for any single row within a similar population of cane stalks. The individual errors of all border rows in this area have been calculated and appear in Table II; they are broken down into 6 groupings to separate the differences in their exposures.

The 10 rows in Group I had each received the low or 120-pound application of nitrogen and were adjacent to rows which had been given the higher level or 200 pounds. It was in this group especially that we had expected that a border effect might be involved which would tend to make the plot yields higher when roots from

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the cane in the border rows "stole" nitrogen from the more heavily fertilized row of the adjacent plot. The results can scarcely be said to have verified this expectation for only in Plot 49, row 1, do we note an amount of positive variation ($e = +52$) from the expected (41.6) which might indicate a border effect of this nature. On two other plots, Nos. 47 and 55, an effect of some nature other than chance is suggested which has apparently reduced the yield of their No. 6 or border row.

TABLE II

ERRORS IN BORDER ROWS (EXPERIMENT 114)

$$\Sigma e = \Sigma \left[(x - x) - (x_t - x) - (x_b - x) \right]$$

Group I	Plot	Rows	Row yield(x)	General mean(x)	Treatment mean(x_t)	Block mean(x_b)	e
	42	1	124	160	157	138	—11
	43	6	151	160	157	151	+ 3
	46	1	131	160	157	156	—22
	47	6	131	160	157	179	—45*
Rows with low nitrogen	49	1	183	160	157	134	+52*
adjacent to high nitrogen	49	6	144	160	157	134	+13
	52	1	185	160	157	182	+ 6
	52	6	157	160	157	182	—22
	54	1	146	160	157	150	— 1
	55	6	134	160	157	190	—53*

Group II							
	41	6	157	160	163	138	+16
	44	1	157	160	163	151	+ 3
	45	6	129	160	163	156	—30
	48	1	153	160	163	179	—29
Rows with high nitrogen	48	6	155	160	163	179	—27
adjacent to low nitrogen	50	1	128	160	163	134	— 9
	51	6	126	160	163	182	—59*
	53	1	155	160	163	150	+ 2
	53	6	165	160	163	150	+12
	56	1	173	160	163	190	—20

Group III							
Rows with low nitrogen	42	6	209	160	157	138	+74*
adjacent to crop cane	43	1	130	160	157	151	—18
	54	6	182	160	157	150	+35

Group IV							
Rows with high nitrogen	41	1	142	160	163	138	+ 1
adjacent to crop cane	44	6	205	160	163	151	+51*
	50	6	141	160	163	134	+ 4

Group V							
Rows with low nitrogen	47	1	163	160	157	179	—13
adjacent to ditch	55	1	166	160	157	190	—21

Group VI							
Rows with high nitrogen	45	1	162	160	163	156	+ 3
adjacent to ditch	51	1	188	160	163	182	+ 3

Expected $e = 2.01 \times 20.7 = 41.6$ tons.   * = significant.

In Group II we have 10 rows fertilized with high nitrogen which adjoin low nitrogen plots. Row 6 in plot 51 has an error which is considerably larger than it should be and this together with the record of its low yield might lead us to imply that it had lost some of its nitrogen to the adjacent row 1 of plot 52, if it were not that we have already seen from Group I that this row was apparently not benefited. Hence it would not be wise to assume any proved border effect for rows in this group.

In Groups III and IV there is no reason for any border effect since the fertilization of the crop cane was identical with that of the border row in the test plots which adjoin it. Hence the reason for the high error in row 6 of both plots 42 and 44 is purely speculative, but indicative of a faulty separation of cane by the individual cutter who harvested both of these rows.

The data in Groups V and VI are too scanty for discussion but are offered at this time merely for record.

The evidence from these 2 tests is somewhat contradictory but we believe that the difference in their 2 plans of fertilization supplies the reason. Thus when large cane yield differences are expected, such as would be the case when a real deficiency in some growth factor exists, there is a good likelihood that border effect will influence yield comparisons, but where expected yield differences are apt to be small, such as would be the case in most of our Grade A "Amounts" tests, this border influence may not be a very large one even if it exists at all. However, the best procedure is to admit the possibility of its existence and to use those features of an intelligent experimental technique that will tend to reduce border effect to a minimum.

Mosquitoes and Some Other Noxious Flies That Occur In New Caledonia

By Francis X. Williams

Eleven species of mosquitoes are now recorded from New Caledonia. These are discussed in the present paper as well as the occurrence of certain other noxious flies found there.

In May 1940 the Experiment Station of the Hawaiian Sugar Planters' Association sent the writer to New Caledonia to investigate the insects that affect agriculture and the health of man as well as to add data on the general geographical distribution of insects in the Pacific. The information thus acquired during a four-month stay on this island has a direct bearing on the Hawaiian problem of quarantine against foreign insects. With air and sea traffic on the increase, it will become more and more difficult to prevent the accidental introduction of insect pests to our shores. Some of these new pests, should they reach Hawaii alive, would find very suitable breeding places. This is particularly true of mosquitoes, and while malarial mosquitoes *(Anopheles)* seem to be absent in New Caledonia itself—although present in the New Hebrides some 200 miles or more to the north and eastward—other and very annoying species occur there but not in Hawaii. Two species of salt marsh or lagoon mosquitoes, viz. *Aedes vigilax* and *Culex sitiens* are at least at times very common about Noumea, the capital city and chief seaport of New Caledonia. Were these two mosquitoes introduced here they might readily become established in such a large area as Pearl Harbor and in numerous other places along our shores.

New Caledonia—area 6,296 square miles—is an elongate and rugged island that lies just within the Tropic of Capricorn in the southwest Pacific. Many localities on it were visited. I went as far north as Nepoui on the west coast and Hienghene on the east, and made a brief stop at the Isle of Pines, off the southern extremity. More time was spent about Noumea, well to the south, than anywhere else. The collections are far from complete; they were made during the cooler part of the year, some of the visits were short, and the more tropical northern extremity of the island was not seen.

In 1922 Edwards (10) listed and discussed 8 species of mosquitoes from New Caledonia as follows:

Mucidus kermorganti (Laveran)
Aedes (Stegomyia) argenteus Poiret*
Aedes (Ochlerotatus) vigilax (Skuse)
Aedes (Finlaya) notoscriptus (Skuse)
Taeniorhynchus (Coquillettidia) brevicellulus Theo.
Culex sitiens Wied.
Culex fatigans Wied.*

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* Also found in Hawaii. *Culex fatigans* is the same as *Culex quinquefasciatus*, and *Aedes argenteus* is the same as *Aedes aegypti*.

Rachionotomyia caledonica, sp. n.

Since that time three others have been definitely recognized or added, making a total of 11 species, viz:

Mucidus alternans (Westw.)

Aedes (Aedomorphus) vexans (Meig.)

Culex (Neoculex) pseudomelanoconia Theo.

Nine species, including a new record, were taken on the present survey. Most of these mosquitoes are found elsewhere and some are widely distributed. *Mucidus kermorganti* Laveran has thus far been recorded only from New Caledonia, although it may be but a variety of another species of wider distribution (Edwards 11), while *Tripteroides caledonica* (Edwards) occurs also in the New Hebrides. I, myself, took no *Anopheles,* or malarial mosquitoes, in New Caledonia nor heard of any case of their presence there.

Much of the literature referring to mosquitoes chiefly of the Australasian and Oriental regions has not been available, but those works that were consulted are listed at the end of this paper.

There are many types of breeding places for mosquitoes in New Caledonia. Particularly on the west coast there are mangrove swamps that have occasional stagnant pockets devoid of fish. In the yards and gardens one may find barrels and tanks harboring mosquito larvae. More or less temporary, grass-margined pools occur among the fore hills and roadsides and both clear and sluggish streams are to be found as well as fresh-water swamps. There are also some water-holding plants such as *Nepenthes* wherein the larvae may breed.

Some of the mosquitoes in the collection are reared specimens and it is believed that all of these are correctly associated in regard to their immature and adult stages. All the specimens were determined by the writer.

Fig. 1. *Tripteroides caledonica,* female. Side view of thorax. Most of the bristles are omitted.

Tripteroides (Mimeteomyia) caledonica (Edwards)

Rachionotomyia caledonica Edwards, F. W., (10, pp. 100–101), 1922. New Caledonia: Houailou (Montague), June and July 1914, bred from pitcher of *Nepenthes*.

This is a rather slender, neat-looking mosquito with a very long dusky proboscis. It is not heavily scaled and the brownish thorax has two wide stripes of narrow white scales on the side (Fig. 1), the upper stripe being joined in front; the abdomen is nearly black with narrow white bands and the legs except at the base are uniformly dusky. This insect stands or rests quite steeply, head downwards in much the same way as does *Anopheles*.

A single female of this mosquito was taken at Hienghene, well up the east coast, on October 5, 1940. This locality is near Houailou where this species was first taken by Montague in 1914. A fair series was bred in late October and early November 1940, from the pitchers of a species of terrestrial *Nepenthes* plant growing as a

Fig. 2. A species of pitcher plant *(Nepenthes)* on a rocky hillside of southern New Caledonia. Near the center of the picture are three "pitchers", one clearly showing the lid, while somewhat to the left is a pitcher placed in a large vial. The mosquito, *Tripteroides caledonica*, breeds in the liquid in the base of the pitchers. Photo by Louisa Clark Williams.

small colony on a sheltered slope of a ridge leading to a lighthouse at Prony Bay, at the southern extremity of the island. These low plants (Fig. 2) with a portion of their leaves modified pitcher-like, gracefully cylindrical and from 2½ to 5½ inches tall, also bear normal leaves, and flowers on separate stalks. The pitchers contained a rather syrupy liquid in their basal part, including the stem for some distance. *Tripteroides caledonica* larvae and pupae of pale color were active in this liquid. In addition, a number of other insects and a small skink lizard had been trapped in the smooth-walled containers, and had perished and in many cases were well on the way to distintegration in the plant's fluid. Conspicuous among the trapped insects were the ordinary hive bee *(Apis mellifera* L.), some of the smaller native bees, two small spider wasps (Psammocharidae), an ichneumonid wasp, ants, muscoid flies, and a green lacewing (Chrysopidae). In a small forest down the slope was a climbing *Nepenthes* with larger pitchers and likewise containing mosquito young.

Buxton and Hopkins (4) refer to this species *(Rachionotomyia caledonica)* as common in the northern part of the New Hebrides. Details of the anatomy of the larvae (Fig. 3) taken by me from *Nepenthes* plants at Prony Bay do not altogether agree with their figure of the terminal segment (Text Fig. 18, A) but this species
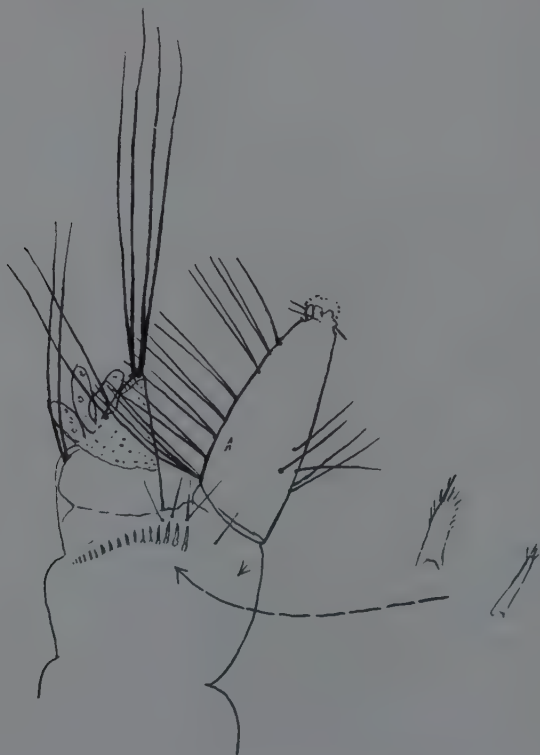

Fig. 3. *Tripteroides caledonica*, larva, tail end.

is admittedly subject to some variation in the larval stage. In my specimens the pecten or the breathing tube is very incomplete, the spines perhaps having been rubbed off. In the New Hebrides the authors above mentioned (4) found this species—identified by F. W. Edwards—breeding in tree holes containing water, i.e. p. 76 ". . . in large numbers in a narrow, deep cavity between the main branches of a *Poinciana* tree". Elsewhere, species of *Tripteroides (Rachionotomyia)* have been found breeding in *Nepenthes*, in tree holes, in an "Old coconut husk with the top cut off for drinking" (Paine 34), in bamboo stubs, in an old kerosene tin, etc. Here they are often associated with other mosquitoes.

Lloyd in his book *The Carnivorous Plants* (28) says, p. 51, "The species of *Nepenthes* are found scattered throughout the tropics of the Old World with the center of distribution in the region of Borneo, being found as far East as N. Australia and New Guinea, and to the West in Ceylon and Madagascar, its extreme outpost (Danser)". A number of species of insects are associated with these interesting plants; to further quote Lloyd, p. 78, "The nepenthebionts include the remarkable number of 26 species; of the *Phoridae* 6, *Chironomidae* 1, and of the *Culicidae* 19." "They feed on the animal detritus found there." At Singapore, Edwards (14, p. 337) found 16 species of mosquitoes, representing 3 genera breeding in pitcher plants.

Lloyd gives a good bibliography on *Nepenthes*.

Mansonia (Coquillettidia) brevicellulus (Theobald)

Taeniorhynchus brevicellulus Theobald, F. V., Mon. Cul. II, p. 212, 1901.
(Recorded by Theobald as *Chrysoconops acer* Walk.)

This is a moderately large pale brownish, naked-looking mosquito with the abdomen showing a purple gloss. Specimens were collected near St. Louis, New Caledonia in July. Most of them were flushed from a grassy swamp. This species occurs in Papua, New Caledonia, Fiji, and the Oriental Region (Taylor 37). The early stages were not found but it is known that the larvae of *Taeniorhychus* insert their sharply pointed siphon into the tissues of aquatic plants and thereby obtain oxygen without having to come to the surface.

Mucidus alternans (Westwood)

Culex alternans Westwood, D. O., 1835. Ann. Soc. Ent. France, IV, p. 681, (Nova Hollandia).
Mucidus alternans (Westwood). "New Caledonia, Noumea (J. J. Walker, 1 ♀ in British Museum)".

Edwards (11) in writing of this species says (p. 367), "A large species which could not be confused with any other in the Australian fauna, owing to the shaggily-scaled legs with white rings on the tibiae as well as the tarsi. Larvae in shallow swamps."

Cooling (5) who observed this mosquito in Queensland says, p. 18, "Almost invariably are the larvae of this species to be found in salt marshes." "The larvae of *M. alternans* are inordinate in their 'cannibalistic' desires, for they will greedily devour the larvae of their own species if other larval forms are not available." This desirable habit goes no farther however, for as an adult this day-flying species is

"... famous for its biting powers ..." (Froggatt 19, p. 290). This conspicuous species was not taken by me.

The larva is well figured by Cooling (5) and by Woodhill and Pasfield (41). The siphonic index (the ratio of the length of the siphon—minus the terminal valves and the acus—to its width at the base) is 3.1–3.3 (Cooling 5), and the anal gills are small and narrow.

Mucidus kermorganti (Laveran)

Culex kermorganti Laveran, C. R., LIII, p. 568, 1901

Edwards (11, p. 367), "New Caledonia: Noumea (Laveran); Calama (Delacour)."

Edwards thinks this may be a form of the preceding. It has not been taken outside of New Caledonia. Not taken by the writer.

Aedes (Stegomyia) aegypti (Linnaeus)

Linnaeus 1762. Hasselquists' Reise nach Palestina, p. 470 *(Culex)*. (= *Culex argenteus* Poiret, 1787; *Culex fasciatus* Fab. 1805; *Culex calopus* Meig. 1818; etc.)

Edwards (10) lists this species in his Culicidae of New Caledonia, *(A. argenteus)*. The present writer took five males and twelve females of this widely distributed yellow fever and dengue-spreading mosquito, all from Noumea, the majority being taken indoors, July, August, and September 1940.

Fig. 4. *Aedes aegypti*, thorax, dorsal view. Noumea, New Caledonia.

This is the species with the silvery lyriform markings on the top of the thorax (Fig. 4). In and about habitations it commonly breeds in rain-water tanks, saucers of flower pots and other artificial containers; it also breeds in water-holding plants

and in tree cavities. The eggs of *aegypti*—as well as others of the same genus—are known to be drought resistant over a long period. The larva has the comb scales with strong lateral barbs. Buxton and Hopkins (4, p. 114) consider *Aedes aegypti* as well as *Culex quinquefasciatus* (= *fatigans*) to be recent immigrants in Melanesia and Polynesia.

Aedes (Finlaya) notoscriptus (Skuse)

Culex notoscriptus Skuse. Proc. Linn. Soc. N.S.W., (2) III, p. 1738, 1889. Described from New South Wales, Australia.

Edwards (10, p. 100) records, "A single female was collected by Mr. Montague 15 miles inland on the Houailou River."

The writer collected two females at light at Noumea, September 27, 1940.

The back of the thorax is marked lyre-like somewhat as in *A. aegypti* but lines are much finer and there is only a single median line (Fig. 5). The scales comprising the larval comb are apically rounded and finely fringed (Woodhill and Pasfield 41, p. 204), (Cooling 5, p. 23). Its breeding habits are much as in the preceding species.

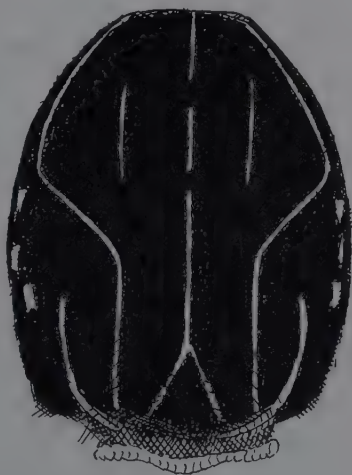*A. notoscriptus* is well-distributed over the Australian region.

Fig. 5. *Aedes notoscriptus*, thorax, dorsal view. Noumea, New Caledonia.

Aedes (Aedomorphus) vexans (Meigen)

Culex vexans Meigen, Syst. Beschr. VI, p. 241, 1830.
Ochlerotatus vexans Edwards, Bull. Ent. Res., VII, pp. 218–219, 1917.

This is a non-domestic nocturnal species having a wide range in tropical and temperate countries. A single pair was taken at Noumea in 1940. Larvae were found in a pool in the hills behind Noumea. Of this species in Fiji, R. W. Paine (34) says. p. 22. "It breeds in puddles on the ground which accumulate after heavy

rain and which, in the writer's experience, are always edged by grasses or other short forms of vegetation . . ."

This mosquito considerably resembles *Aedes (Ochlerotatus) vigilax* Skuse, a common and annoying salt marsh mosquito also occurring in New Caledonia. The male *vexans* is readily separable from *vigilax* by hypopygial characters (Fig. 6). I have seen no male *vigilax*. The single female *vexans* taken has the proboscis prac-

Fig. 6. *Aedes vexans*, aedeagus. Noumea, New Caledonia.

tically unbanded though largely pale-scaled beneath (Fig. 7, B), the vertex of the head has much fine pale hair and fewer dark upright forked scales while there are practically no pale scales on the wings, as are present, to the contrary, on the wings of *vigilax*. The pale abdominal bands hardly show the bilobed condition, as described for typical *vexans* females. The larva of *vexans* has been figured by a number of authors and is readily separable from other species known from New Caledonia, etc., by the two distal scales of the pecten being rather larger and isolated (Fig. 8). The anal gills are long and pointed.

Aedes (Ochlerotatus) vigilax (Skuse)

   Culex vigilax Skuse, Proc. Linn. Soc. N.S.W., (2) III, p. 1731, 1889.
   Edwards, F. W., Bull. Ent. Res., XIV, p. 375, 1924.

Fig. 7. A—*Aedes vigilax*, female, proboscis, from above. La Foa, New Caledonia. B—*Aedes vexans*, female, proboscis, from above. Noumea, New Caledonia.

At the time of our visit this was the most numerous and annoying of all mosquitoes, biting so persistently during the daytime as to make the collecting of insects—other than its own species—along the seashore around Noumea, a very interrupted procedure.

R. Hamlyn-Harris (20) says, on page 229, "*Aedes vigilax* is the chief long-distance mosquito in Australia and it outnumbers any other pest mosquito in the coastal areas." I found it breeding in a stagnant part of a mangrove swamp at Noumea where it was associated with *Culex sitiens* and a species of *chironomid* fly. Buxton and Hopkins (4) found this species very common and troublesome both day and evening, June 4 and 5, 1925 at Tontouta, on the west side of New Caledonia. It is chiefly an outdoor species.

The larva has very short rounded anal gills (Fig. 9, A)—a character of salt marsh mosquito larvae (Marshall 30, p. 52). The siphon is short, the index as illustrated being approximately 2; this is somewhat greater than that given by Wood-

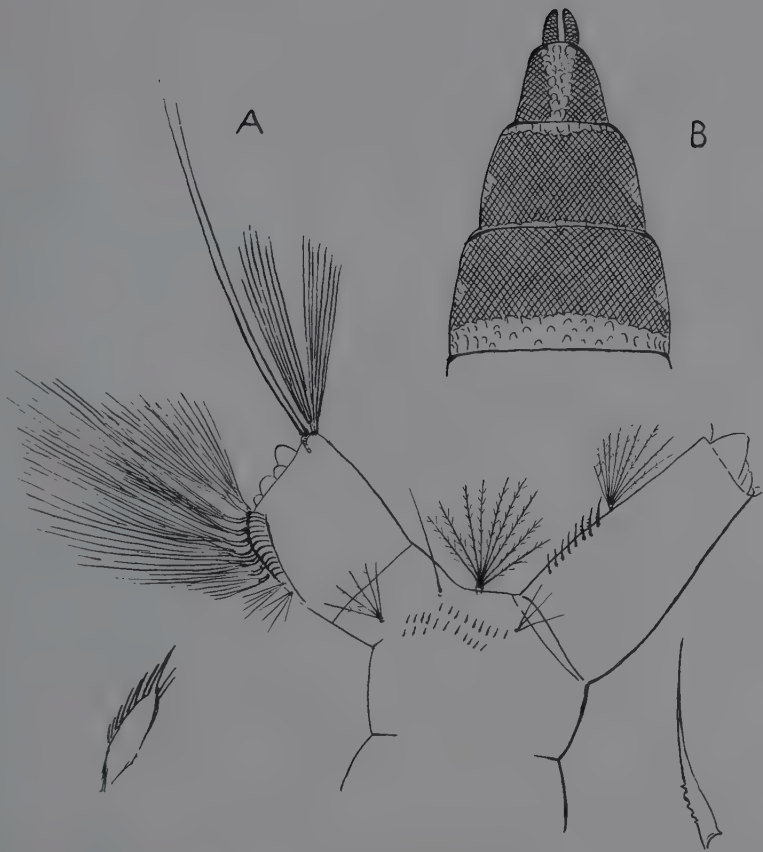Fig. 8. *Aedes vexans*, larva, tail end. Noumea, New Caledonia.

Fig. 9. A—*Aedes vigilax*, larva, tail end. B—female, end of abdomen, from above. Noumea, New Caledonia.

hill and Pasfield (41) and by Cooling (5), and much greater than that given and figured by Brug (2) referring to Dutch-East-Indian mosquitoes—the siphon being "... as long as broad ..."

Hamlyn-Harris (20, pl. vi) gives an excellent figure of the adult, which shows the well-banded legs and the broadly though not very sharply banded proboscis. There is a sprinkling of pale scales on the wings. In Taylor's check list (37) the distribution of *vigilax* is given as "Coasts of Australia, Papua, New Caledonia, Philippine Islands." It has recently been reported by Lever from Fiji (34, pp. 24 and 25, in Paine's "Mosquitoes of Fiji"). The wing denuded of scales and hair is shown in Fig. 10, and the proboscis in Fig. 7, A.

Culex (Culex) sitiens Wied.

Culex sitiens Wiedemann, Aussereurop. Zweifl. Ins. (p. 543), 1828.
Culex sitiens, Edwards, F. W., Bull. Ent. Res., XIV, p. 394, 1924.
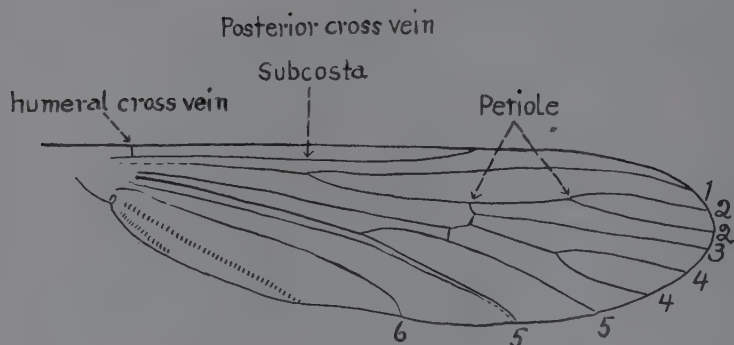
Fig. 10. *Aedes vigilax*, female wing, to show venation.

Buxton and Hopkins, Res. in Polyn. and Melan., p. 79, 1927.
Culex jepsoni Theobald, Ent. XLIII, p. 158, 1910 (Fiji).
MacGregor, M. E., Mosquito Surveys, pp. 167–171, 1927 (quotes Wiedemann's description, etc.)

Somewhat resembling *A. vigilax* but differing from that species in having a strong rather narrow white band on the proboscis (Fig. 11, A) and the legs less conspicuously white-banded, etc. It is a night-biting, often domestic, mosquito that was found associated with *A. vigilax* in the brackish water of a mangrove swamp at

Fig. 11. *Culex sitiens*, female. A—proboscis, from above. B—end of abdomen, from above. Noumea, New Caledonia.

Fig. 12. A—*Culex pseudomelanoconia*, larva, tail end. Ba-Houailou, New Caledonia. B—*Culex sitiens*, larva, tail end. Noumea, New Caledonia.
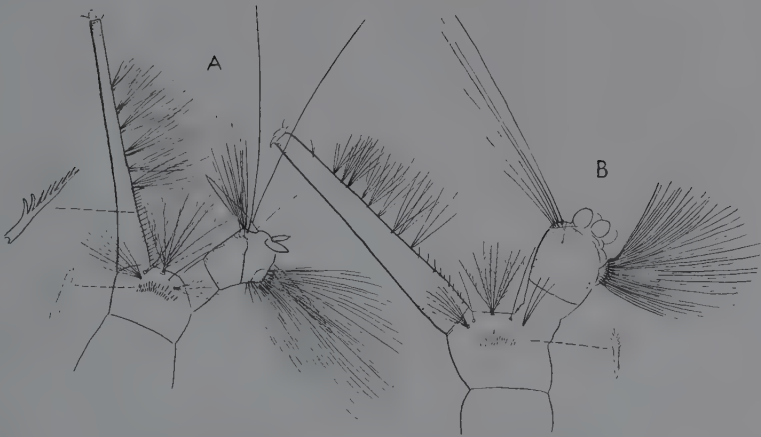

Fig. 13. *Culex sitiens*, female, aedeagus. Noumea, New Caledonia.

Noumea. Adults in the Experiment Station, H.S.P.A. collection are represented by one male and eleven females. The larva has a siphonal index of about 7.1 (Fig. 12, B) and short rounded anal gills. It is figured by Cooling (5) with the siphonal index of 4.5–5.5. Others give the siphonal index as still shorter so that one wonders if the determination of this species is correct. The aedeagus is shown in Fig. 13.

A widely distributed species.

Culex (Culex) quinquefasciatus Say

Culex quinquefasciatus Say, T., Journ. Acad. Nat. Sci. Phila., III, p. 10, 1823.
Culex fatigans Wiedemann, Auss. Zweifl. Ins., 1, p. 10, 1828.
Culex quinquefasciatus. Dyar, H. G., The mosquitoes of the Americas, Carnegie Insti. of Washington, 1928 (pp. 380–383).

Noumea and St. Louis; larvae, Noumea; in tank in garden. Oua Tom; stagnant pool.

The siphonal index (Fig. 14) of this widely distributed night species varies from 3.4 to 6.5 (Woodhill and Pasfield 41, p. 212).
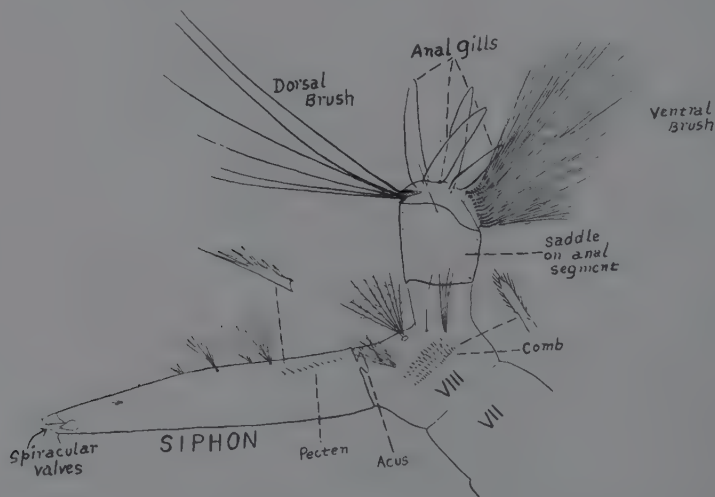
Fig. 14. Culex quinquefasciatus, larva, tail end.

Culex (Neoculex) pseudomelanoconia Theobald

Culex pseudomelanoconia Theobald, F. V., Mon. Cul. IV, p. 416, 1907.

Five females bred from larvae in small rock pools of Ba-Houailou stream, just below the beautiful falls and pool. The larva has a very slender anal siphon and rather long dagger-like anal gills (Fig. 12, A).

A small dark, nearly concolorous species described from South Queensland, Australia. Apparently the first record for New Caledonia.

Although sooner or later the malarial mosquito *Anopheles (Myzomyia) punctu-latus* Dönitz may be found in New Caledonia, I am unable to discover, at the time of this writing, any evidence of its presence there.

The presence or absence of *Anopheles* in New Caledonia has been the subject of some discussion, and the reader is referred to Taylor (37), Buxton (2a, p. 84), Neveu-Lemaire (33, pp. 1197 and 1198), Zimmerman (42, pp. 296 and 297), Mumford (32) and Lever (25 and 27).

SIMULIDAE

(Black Flies)

These are small thickset and usually dark-colored flies with broad wings, the veins of which are strongly developed only towards the anterior or costal border. They breed in streams, requiring rapidly running water for their early stages. Some are great pests often occurring in enormous numbers, and their bites are very irritating. They range well out in the Pacific, occurring in Fiji, the Marquesas and Society Islands, though not occurring in Samoa and the Hawaiian Islands.

The writer found a few specimens of an unidentified species, less than two millimeters long, and apparently a new record for New Caledonia. A note on this fly reads as follows: "Yahoue Valley, August 29, 1940: While seated in the forest sorting out a catch of insects, some *Simulium* flies alighted on my leather jacket and made as if to bite it, mistaking it perhaps for the skin of some large quadruped." One or two other specimens were taken on a mountain height known as Dzumao, farther inland from Noumea. These flies were not troublesome.

Species of Simulidae, however, are known to be intermediate hosts for certain diseases of man and other animals (Herms 22, pp. 140–142).

TABANIDAE

(Horseflies)

Several species of these large flies are found in New Caledonia. They seemed to be coming into season in late October and in November. *Tabanus rubricallosus* Ricardo (Fig. 15), ½-inch long and largely grayish was fairly common about the beaches of the Isle of Pines, at the time of our visit there in late October 1940.

Horseflies are often if not usually vicious biters, attacking man, horses, cattle and other domestic animals. Certain species are sometimes involved in the distribution of anthrax among cattle and sheep and of surra among horses. (See Essig, 21, p. 767, and Edwards, Oldroyd and Smart 16, pp. 75–76.) On the Isle of Pines, New Caledonia, an outbreak of malignant pustules on cattle was suspected of having been transmitted by *Pangonia neocaledonica* Megnin (Tabanidae), and by the ordinary stable fly *Stomoxys calcitrans* (L.). (See Megnin and Germain, 31.)

The larvae of Tabanidae are mainly aquatic, subaquatic, or living in damp soil; they are often found in mud along the edges of ponds and marshes, not excepting salt marshes, some species occurring among seaweed and in the moist sea beach sand or mud.

It is easy to see that certain tabanid flies once introduced, would find suitable breeding places in the lowlands of the Hawaiian Islands.

Fig. 15. A horsefly *(Tabanus rubricallosus)* from the Isle of Pines. Length of body 13 mm. Photo by W. Twigg-Smith.

MUSCIDAE
(Houseflies, Etc.)

Musca vicina Macq.

Noumea and Isle of Pines. Not particularly abundant.

The vertex is narrower than in *M. domestica* (see Patton, 1931, II, pp. 595–596).

Stomoxys calcitrans (L.)

The familiar stable fly; Noumea.

I saw no horn flies *(Lyperosia)*, a serious pest of horses and cattle in many countries.

HIPPOBOSCIDAE
(Louse Flies, Flat Flies)

Hippobosca equina L.

This flat leathery fly is a pest on horses and cattle, usually preferring the former. It may congregate in large numbers on its host, particularly where the skin

is thinnest and less hairy, as between the hind legs near the tail. It clings very firmly and is dislodged with difficulty.

This fly is viviparous, the egg hatching within the body of the female and developing there until full-grown when it is extruded to pupate immediately. It is common in many parts of the Old World. At present *H. equina* is known in Oceania, from New Caledonia, Loyalty Islands, Fiji, and New Hebrides only (Bequaert 1, p. 258). The writer secured this fly on a horse at Noumea and on a colt on the Isle of Pines.

For further literature relating to this fly see Buxton and Hopkins (4, pp. 56–57), and Edwards, Oldroyd and Smart (16, pp. 122–139).

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The Synthesis of Sucrose in the Sugar Cane Plant—III

The effects of specific inhibitors upon the interconversion of glucose and fructose and the formation of sucrose in detached blades of the sugar cane plant

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By Constance E. Hartt

1. *The use of specific inhibitors:*

The studies presented herein were undertaken for the purpose of learning something of the system whereby sucrose is synthesized in the plant. For this purpose many chemicals have been used, which have been found by other workers to be more or less specific inhibitors of physiological processes. Many investigators have used chemicals considered to be specific inhibitors of physiological processes as tools for elucidating the mechanism of reactions in plants and animals. One of the objections to the method is that the inhibitor may after all not be specific. The justification of applying the results obtained in studies with one organism to investigations with another organism may also be questioned. In the study reported herein, no attempt has been made to prove the specificity of a given poison for a given reaction or type of reactions. The evidence has been taken entirely from the literature and without exception has come from organisms other than sugar cane. This should be understood at the start, as our aim is not to present definite proof, but to build up a picture of a possible mechanism of the formation of sucrose.

If a poison which is known to inhibit a certain enzyme reaction has no effect upon synthesis, then we may conclude that that particular enzyme reaction does not form part of the mechanism of synthesis. If a poison which is known to inhibit a certain enzyme reaction increases synthesis, then it is possible that that particular reaction constitutes a competitor for glucose, *i.e.*, it uses up the glucose which might otherwise have formed sucrose. But if a poison which is known to inhibit a certain enzyme reaction decreases synthesis, then it is possible that the enzyme reaction is in some way a necessary part of the mechanism of synthesis. Of course another possibility remains, that in addition to its known effect the poison in question may also exert other as yet unknown effects.

The aim is therefore to build up a picture of the effects of poisons, in an attempt to formulate a theory of the mechanism of synthesis of sucrose. Such a theory would then have to be tested by other means.

Since studies reported in the first two parts of this paper indicated that aeration and phosphate are essential for interconversion and synthesis, the poisons used in this investigation have been chiefly chemicals known to inhibit steps in the respiratory processes and in phosphorylation. The following is a list of inhibitors discussed in this report: cyanide, pyrophosphate, azide, 8-hydroxyquinoline, iodoacetic acid, arsenite, selenite, fluoride, malonate, acenaphthene, chloroform, dinitrophenol,

ethyl alcohol, histidine, phloridzin, quinine, urethane, brilliant alizarine blue, rosin-duline GG, iodine, silver nitrate, copper sulphate, sodium diethyldithiocarbamate, potassium ferricyanide, thymol, sodium pentachlorophenate, and sodium chlorate.

All of the experiments recorded herein were conducted with blades detached from the plant.

Because inhibiting the formation of fructose diphosphate inhibits the formation of sucrose, whereas inhibiting the breakdown of fructose diphosphate increases synthesis, we are led to conclude that fructose diphosphate is a stepping stone in the formation of sucrose by the sugar cane plant.

2. *Cyanide:*

Cyanide is perhaps the best known of the respiratory inhibitors. The effects of cyanide have been reviewed by Commoner (9),* Elvehjem (23), Oppenheimer (67), and others. Cyanide forms a complex with ferric iron preventing its reduc-tion to ferrous iron. Since the interchange between ferric and ferrous iron is the essential feature of the action of many of the respiratory catalysts, a large part of the respiration of both plants and animals is sensitive to cyanide. The following enzymes are partially or completely inhibited by cyanide: Warburg's Atmungsfer-ment ($=$ cytochrome oxidase $=$ indophenol oxidase $=$ pheohemin), peroxidases, catalase, uricase, ascorbic acid oxidase, tyrosinase, dopa oxidase, orthophenol oxi-dase, xanthine dehydrogenase, and probably others. Some types of dihydroxy-maleic acid oxidase are inhibited by cyanide, according to Boswell and Whiting (6). That part of respiration involving the yellow enzyme and triphosphopyridine nucleo-tide is cyanide-stable. Respiration is inhibited by 10^{-4} M CN, and fermentation by 10^{-2} M, according to Oppenheimer. Dixon and Elliott (19) stated that M/1000 CN gave maximum inhibition of respiration of animal tissues. Leloir and Dixon (50) used M/500 CN in their study of dehydrogenases. Commoner found that the percentage of inhibition of respiration of baker's yeast by a given concentration of cyanide is greater in the presence of sugar than in its absence. Leloir and Dixon found that cyanide significantly increased the activity of hexose diphosphate dehy-drogenase, an effect which they attributed to the presence of traces of heavy metals. Hexokinase, the enzyme which catalyzes the transfer of phosphate from adenosine triphosphate to glucose, is unaffected by cyanide, according to Case (8). Leonard (51) found that corn blades given 0.001–1.0% KCN or NaCN showed equal syn-thesis of sucrose from glucose.

Several tests have been conducted in which blades of sugar cane were supplied with cyanide along with glucose, fructose, or both. The results of one experiment, in which 0.049 gms. NaCN per liter were used, are reported in Table I. The gains in sugars and the synthetic efficiencies are shown in Table II. It is evident that

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* Numbers in parentheses refer to literature citations at the end of the fourth part of this paper.

TABLE I

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE, FRUCTOSE, OR BOTH, WITH AND WITHOUT 0.049 GMS. NaCN PER LITER, FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	69.64±0.057	0.538±0.008	2.459±0.018	3.126±0.010
Water	70.00±0.081	0.302±0.017	2.247±0.033	2.668±0.018
NaCN	69.20±0.076	0.475±0.032	1.746±0.009	2.313±0.022
Glucose	69.05±0.052	0.817±0.019	4.288±0.010	5.332±0.009
Fructose	68.92±0.067	0.924±0.001	4.541±0.022	5.705±0.023
Both	69.55±0.048	1.095±0.024	4.199±0.021	5.516±0.001
Glucose + NaCN	67.28±0.071	0.828	3.987	5.025
Fructose + NaCN	66.51±0.019	0.875±0.001	4.061±0.013	5.149±0.004
Both + NaCN	67.87±0.019	0.917±0.018	3.977±0.002	5.104±0.021

TABLE II

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH GLUCOSE, FRUCTOSE, OR BOTH, WITH AND WITHOUT 0.049 GMS. NaCN PER LITER, FOR 24 HOURS, CALCULATED FROM TABLE I

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Water	—0.458	—0.212	0
NaCN	—0.813	—0.713	0
Glucose	2.206	1.829	82.91
Fructose	2.579	2.082	80.72
Both	2.390	1.740	72.80
Glucose + NaCN	1.899	1.528	80.46
Fructose + NaCN	2.023	1.602	78.84
Both + NaCN	1.978	1.518	76.74

cyanide did not inhibit the synthesis of sucrose. When weaker concentrations of cyanide were used (5–25 p.p.m. NaCN) the synthetic efficiency was generally increased a little, but in a few tests there was a slight decrease. For example, in one test the synthetic efficiencies were as follows: with glucose, 75.34; with glucose + 5 p.p.m. NaCN, 77.89; with glucose + 10 p.p.m. NaCN, 73.00; and with glucose + 25 p.p.m. NaCN, 81.33. The percentages of fructose and glucose in the blades supplied with 0.049 gms. NaCN per liter are presented in Table III, which shows no evidence of inhibition of interconversion of glucose and fructose.

TABLE III

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLU-COSE, FRUCTOSE, OR BOTH, WITH AND WITHOUT 0.049 GMS. NaCN PER LITER, FOR 24 HOURS

Series	Fructose	Glucose
Intial control	0	0.538±0.008
Water	0.149±0.071	0.183±0.039
NaCN	0.407±0.012	0.068±0.020
Glucose	0.606±0.016	0.211±0.036
Fructose	0.527±0.027	0.397±0.017
Both	0.672±0.027	0.423±0.002
Glucose + NaCN	0.510±0.011	0.329
Fructose + NaCN	0.531±0.124	0.344±0.003
Both + NaCN	0.578±0.171	0.339±0.025

It is evident from these results that cyanide inhibited neither the interconversion of glucose and fructose nor the formation of sucrose. Yet the cyanide was strong enough to inhibit the cyanide-sensitive respiratory processes. It would appear that the Warburg-Keilin system of oxidase and the cytochrome complex is not an essential component of the mechanism of synthesis of sucrose.

3. *Pyrophosphate:*

Pyrophosphate inhibits reactions catalyzed by iron or copper. However, it does not inhibit cytochrome oxidase. It has no effect on the respiration of baker's yeast. Leloir and Dixon (50) found that pyrophosphate strongly inhibits succinic dehydrogenase, but does not inhibit any other dehydrogenase studied. Dixon and Elliott (19) found that 0.01 M pyrophosphate inhibited the respiration of liver 30–70 per cent. The action of pyrophosphate has been studied chiefly with animal tissues, and no paper dealing with the effect of pyrophosphate upon the respiration of higher plants has come to the attention of the author. The effects of pyrophosphate have been reviewed by Elvehjem (23) and Oppenheimer (67).

The effect of pyrophosphate upon the formation of sucrose from glucose was studied in blades supplied with 8 grams sodium pyrophosphate per liter, and the results are recorded in Table IV. The gains in sugars and the synthetic efficiencies are presented in Table V. The percentages of fructose and glucose are reported in Table VI. Pyrophosphate did not inhibit either the conversion of glucose to fructose or the formation of sucrose. This finding indicates that the reactions catalyzed by iron or copper do not take part in interconversion or synthesis. Since succinic dehydrogenase is inhibited by pyrophosphate, and synthesis is not, succinic dehydrogenase is not essential for the synthesis of sucrose.

TABLE IV

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT 8 GRAMS $Na_4P_2O_7.10$ H_2O PER LITER, FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	68.24 ± 0.029	0.884 ± 0.009	2.585 ± 0.008	3.606 ± 0.019
Glucose	69.32 ± 0.005	1.773 ± 0.007	6.453 ± 0.014	8.566 ± 0.022
Glucose + pyrophosphate	69.37 ± 0.100	1.458 ± 0.011	5.866 ± 0.029	7.634 ± 0.042

TABLE V

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT 8 GRAMS $Na_4P_2O_7.10H_2O$ PER LITER, FOR 24 HOURS, CALCULATED FROM TABLE IV

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	4.960	3.868	77.98
Glucose + pyrophosphate	4.028	3.281	81.45

TABLE VI

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT 8 GRAMS $Na_4P_2O_7.10H_2O$ PER LITER, FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.814 ± 0.029		0.070 ± 0.020	
Glucose	1.197 ± 0.019	0.383	0.576 ± 0.026	0.506
Glucose + pyrophosphate	1.027 ± 0.008	0.213	0.431 ± 0.003	0.361

4. *Azide:*

Sodium azide (Na N_3) slightly accelerates alpha-phosphoglycerol dehydrogenase, according to Elvehjem (23). Sodium azide is a very strong inhibitor of catalase prepared from horse liver. Keilin and Hartree (43) state that azide stabilizes the reduced intermediate compound and thus inhibits the catalase reaction. It also inhibits the respiration of yeast. Oppenheimer (67) states that azide reversibly inhibits catalase and also inhibits peroxidase, indophenol oxidase and phenolase. Keilin and Hartree used 0.001 gram sodium azide for 2 cc. strong catalase solution.

The effect of sodium azide upon sugar transformations in cane blades was studied using the same strength of azide used by Keilin and Hartree. The results are presented in Table VII. The gains in sugars and the synthetic efficiencies are reported in Table VIII. The percentages of fructose and glucose are recorded in Table IX. Sodium azide did not prevent either the conversion of glucose to fruc-

TABLE VII

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT 0.05 GRAMS NaN_3 PER LITER, FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	66.02±0.024	0.556±0.029	2.824±0.000	3.529±0.004
Water	67.88±0.019	0.571±0.007	2.437±0.015	3.137±0.023
NaN_3	67.57±0.052	0.488±0.015	2.367±0.021	2.980±0.038
Glucose	65.65±0.057	0.749±0.008	4.268±0.016	5.242±0.008
Glucose + NaN_3	65.96±0.019	0.997±0.003	4.770±0.013	6.019±0.017

TABLE VIII

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT 0.05 GM. NaN_3 PER LITER, FOR 24 HOURS, CALCULATED FROM TABLE VII

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Water	—0.392	—0.387	
NaN_3	—0.549	—0.457	
Glucose	1.713	1.444	84.29
Glucose + NaN_3	2.490	1.946	78.15

TABLE IX

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT 0.05 GM. NaN_3 PER LITER, FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.144±0.000		0.412±0.004	
Water	0.301±0.001	0.157	0.270±0.005	—0.142
NaN_3	0.304±0.000	0.160	0.184±0.015	—0.228
Glucose	0.282±0.002	0.138	0.467±0.009	0.055
Glucose + NaN_3	0.393±0.009	0.249	0.603±0.006	0.191

tose or the formation of sucrose, although it did decrease the synthetic efficiency a little. Catalase, peroxidase, indophenol oxidase and phenolase probably play no important part in either interconversion or synthesis.

5. *8-hydroxyquinoline:*

This is a copper poison and inhibits the action of enzymes containing or depend-

ing on copper. Elvehjem (23) states that polyphenolases, potato oxidase, phenol oxidase, laccase, catechol oxidase, and tyrosinase are all copper proteinates. Ramasarma (72) says that it also inhibits ascorbic acid oxidase.

Blades were supplied with glucose with and without 8-hydroxyquinoline (25 p.p.m.) for 24 hours, and the results are presented in Table X. The gains in sugars and the synthetic efficiencies are reported in Table XI. The percentages of fructose and glucose are recorded in Table XII. These results show that 25 p.p.m. 8-

TABLE X

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT 25 P.P.M. 8-HYDROXYQUINOLINE, FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	70.65±0.019	0.603±0.019	1.944±0.008	2.649±0.010
Glucose	70.74±0.038	1.206±0.018	5.133±0.006	6.610±0.011
Glucose + 8-hydroxyquinoline	70.19±0.000	1.175±0.000	4.911±0.005	6.344±0.005

TABLE XI

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT 25 P.P.M. 8-HYDROXYQUINOLINE, FOR 24 HOURS, CALCULATED FROM TABLE X

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	3.961	3.189	80.50
Glucose + 8-hydroxyquinoline	3.695	2.967	80.29

TABLE XII

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT 25 P.P.M. 8-HYDROXYQUINOLINE, FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.873±0.009		0	
Glucose	0.490±0.006	−0.383	0.716±0.024	0.716
Glucose + 8–hydroxyquinoline	0.768±0.012	−0.105	0.406±0.012	0.406

hydroxyquinoline did not inhibit either the conversion of glucose to fructose or the formation of sucrose, which indicates that the oxidases mentioned in the preceding paragraph are not essential for conversion or synthesis.

The results with cyanide, pyrophosphate, azide, and 8-hydroxyquinoline agree in showing that the oxidases, peroxidases, and catalase are not required, either directly or indirectly, for the conversion of glucose to fructose or for the synthesis of sucrose.

6. *Iodoacetate:*

The statement is sometimes made that iodoacetate inhibits fermentation but not respiration. This is not strictly true, as both time and concentration must be considered. Turner (80) states that iodoacetate acts more quickly on fermentation than on respiration. He also states that probably any concentration of iodoacetate which inhibits fermentation will in time also decrease respiration. Data regarding the effect of concentration of iodoacetate upon respiration and fermentation are summarized in Table XIII, which shows that strong iodoacetate inhibits both fer-

TABLE XIII

SUMMARY OF DATA REGARDING EFFECT OF CONCENTRATION OF IODOACETATE
UPON RESPIRATION AND FERMENTATION

Concentration	General effect	Author
.01 M	inhibits aldehyde, succinic, lactic, glycerophosphate, fumaric, alcohol and triosephosphate dehydrogenases, and aldehyde mutase	Elvehjem (23)
.01 M–.002 M	inhibits both fermentation and respiration	Nilson (80)
.005 M	inhibits hexokinase almost completely	Iri (40)
.002 M	inhibits hexokinase incompletely	Iri (40)
.00108 M	inhibits fermentation but only slightly depresses respiration	Turner (80)
.001 M	inhibits fermentation in carrot and yeast	Turner (81)
.001 M	inhibits fermentation and decreases respiration 50%	Engelhardt (25)
.001 M	inhibits fermentation	Elvehjem (23)
<.001 M	specifically inhibits alcohol dehydrogenase and triosephosphate dehydrogenase	Dixon (18)
.0001 M	only fermentation inhibited	Nilson (80)
c .001 M–.0001 M	inhibits only fermentation and maintains respiration	Barker (3)

mentation and respiration, but that very weak iodoacetate inhibits only fermentation.

To find the effect of iodoacetate upon sugar conversions in cane blades an experiment was conducted using 0.0001 M iodoacetate to inhibit only fermentation and 0.01 M iodoacetate to inhibit both fermentation and respiration. The iodoacetic acid was dissolved in alcohol and neutralized with sodium hydroxide. The results are presented in Table XIV. The gains in sugars and the synthetic efficiencies are recorded in Table XV. The fructose and glucose percentages are reported in Table XVI. The weak iodoacetate did not inhibit either the conversion of glucose to fruc-

TABLE XIV

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE
WITH AND WITHOUT 0.0001 M AND 0.01 M IODOACETATE, FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	68.56±0.029	0.737±0.013	2.720±0.008	3.600±0.005
Glucose	69.87±0.000	1.228±0.037	4.937±0.058	6.426±0.024
Glucose + .0001 M IAA	67.60±0.000	1.055±0.004	4.876±0.025	6.188±0.022
Glucose + .01 M IAA	69.43±0.014	3.097±0.012	2.726±0.021	5.966±0.034

TABLE XV

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH
GLUCOSE WITH AND WITHOUT 0.0001 M AND 0.01 M IODOACETATE, FOR 24
HOURS, CALCULATED FROM TABLE XIV

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	2.826	2.217	78.45
Glucose + .0001 M IAA	2.588	2.156	83.30
Glucose + .01 M IAA	2.366	0.006	0

TABLE XVI

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLU-
COSE WITH AND WITHOUT 0.001 M AND 0.01 M IODOACETATE, FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.663±0.008		0.073±0.021	
Glucose	0.462±0.008	−0.201	0.766±0.029	0.693
Glucose + .0001 M IAA	0.738±0.058	0.075	0.317±0.054	0.244
Glucose + .01 M IAA	0.701±0.005	0.038	2.396±0.007	2.323

tose or the formation of sucrose; in fact there was a slight increase in synthetic efficiency in the presence of weak iodoacetate. Strong iodoacetate, however, completely inhibited the formation of sucrose. The large accumulation of glucose in the presence of strong iodoacetate, accounting almost entirely for the gain in total sugars, showed that iodoacetate prevented the conversion of glucose to fructose.

The effect of strong iodoacetate was then studied using glucose, fructose, and both of the sugars. The results are shown in Table XVII. The gains in sugars and the synthetic efficiencies are recorded in Table XVIII. The percentages of fructose and glucose are presented in Table XIX. The synthetic efficiency of 9.60, shown in Table XVIII, where the blades were supplied with both glucose and fruc-

TABLE XVII

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE OR FRUCTOSE WITH AND WITHOUT .01 M IODOACETATE, FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	70.02 ± 0.067	0.806 ± 0.001	2.430 ± 0.005	3.364 ± 0.007
Glucose	71.55 ± 0.062	1.599 ± 0.021	4.883 ± 0.011	6.739 ± 0.032
Fructose	70.74 ± 0.005	1.547 ± 0.019	4.662 ± 0.037	6.455 ± 0.020
Both	70.21 ± 0.019	1.388 ± 0.013	4.790 ± 0.039	6.431 ± 0.029
Glucose $+$ .01 M IAA	71.00 ± 0.033	3.248 ± 0.002	2.497 ± 0.069	5.877 ± 0.071
Fructose $+$ .01 M IAA	70.41 ± 0.005	2.609 ± 0.010	2.509 ± 0.014	5.250 ± 0.004
Both $+$ .01 M IAA	69.16 ± 0.009	2.893 ± 0.023	2.653 ± 0.056	5.685 ± 0.082

TABLE XVIII

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH GLUCOSE OR FRUCTOSE WITH AND WITHOUT .01 M IODOACETATE, FOR 24 HOURS, CALCULATED FROM TABLE XVII

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	3.375	2.453	72.68
Fructose	3.091	2.232	72.20
Both	3.067	2.360	76.94
Glucose $+$ .01 M IAA	2.513	0.067	0
Fructose $+$ .01 M IAA	1.886	0.079	0
Both $+$ .01 M IAA	2.321	0.223	9.60

TABLE XIX

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE OR FRUCTOSE WITH AND WITHOUT .01 M IODOACETATE, FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.294 ± 0.006		0.511 ± 0.005	
Glucose	0.726 ± 0.079	0.432	0.873 ± 0.058	0.362
Fructose	1.035 ± 0.025	0.741	0.512 ± 0.043	0.001
Both	0.885 ± 0.060	0.591	0.503 ± 0.047	—0.008
Glucose $+$ .01 M IAA	0.813 ± 0.000	0.519	2.434 ± 0.002	1.923
Fructose $+$ .01 M IAA	2.076 ± 0.057	1.782	0.533 ± 0.067	0.022
Both $+$ .01 M IAA	1.660 ± 0.049	1.366	1.232 ± 0.025	0.721

tose in the presence of .01 M iodoacetate is not significant, because the gain in sucrose (0.223) was not significant. These results demonstrate the complete inhibitory effect of strong iodoacetate upon synthesis of sucrose, in blades supplied with

glucose, fructose, or both. Glucose accumulated in the blades supplied with glucose, and fructose accumulated in the blades supplied with fructose, indicating that strong iodoacetate inhibits the interconversion of glucose and fructose. However, something more than just interconversion was inhibited by iodoacetate, for the synthesis of sucrose was inhibited even when both glucose and fructose were supplied.

The factor involved in the inhibition of interconversion and synthesis by strong iodoacetate might be one of the dehydrogenases listed in Table XIII, but not succinic dehydrogenase for that is inhibited by pyrophosphate and sodium diethyldithiocarbamate, neither of which inhibits interconversion or synthesis, as shown in this report. The factor involved might be hexokinase, which catalyzes the transfer of phosphate from adenosine triphosphate to glucose.

7. *Arsenite:*

Arsenite is a potent inhibitor of respiratory processes. Szent-Györgyi (78) stated that alcoholic fermentation in yeast is practically unaffected by 0.057 M arsenite, a concentration which almost completely inhibits oxygen uptake. Therefore he said that arsenite makes possible a separation of respiration and fermentation by inhibiting respiration. Indophenol oxidase of liver was quite insensitive to a high concentration of arsenite (0.01 M), indicating that arsenite has no effect on oxygen activation. Arsenite had little effect on hydrogen activation either, according to Szent-Györgyi. Pillai (69) stated that arsenic activated the breakdown of hexose diphosphate in muscle extract, and Harden (60) found that it accelerated fermentation in yeast extract by quicker splitting of fructose diphosphate. Elvehjem (23) said that succinic acid dehydrogenase is almost completely inhibited by arsenite, and Oppenheimer (67) stated that arsenic inhibits the enzyme which attacks ketoglutaric acid and blocks the citric acid cycle at that level. Dixon (18) reported that the reaction, triose phosphate $\rightarrow$ phosphoglyceric acid is coupled with the synthesis of adenylpyrophosphate from inorganic phosphate and adenylic acid. This coupling is broken by arsenic. Since adenylpyrophosphate ($=$ adenosinetriphosphate $=$ cophosphorylase) is required both for the phosphorylation of glucose and for the formation of fructose diphosphate from fructose monophosphate, this adds two more steps in intermediate carbohydrate metabolism which may be inhibited by arsenic.

Several concentrations of sodium arsenite have been used in tests with cane blades. The effect of arsenite upon the formation of sucrose from glucose is shown in Table XX. The gains in sugars and the synthetic efficiencies are presented in Table XXI. The percentages of fructose and glucose are reported in Table XXII.

TABLE XX

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT SODIUM ARSENITE (5 P.P.M.–100 P.P.M. As) FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	73.42±0.043	1.135±0.005	1.849±0.008	3.082±0.013
Glucose	73.11±0.005	2.030±0.011	5.851±0.018	8.189±0.007
Glucose + 5 p.p.m. As	72.23±0.071	2.466±0.017	5.642±0.002	8.406±0.019
Glucose + 25 p.p.m. As	71.85±0.143	4.433±0.032	3.278±0.022	7.884±0.009
Glucose + 100 p.p.m. As	71.60±0.172	6.151±0.060	1.837±0.020	8.084±0.038

TABLE XXI

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT SODIUM ARSENITE (5–100 P.P.M. As) FOR 24 HOURS, CALCULATED FROM TABLE XX

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	5.107	4.002	78.36
Glucose + 5 p.p.m. As	5.324	3.793	71.24
Glucose + 25 p.p.m. As	4.802	1.429	28.56
Glucose + 100 p.p.m. As	5.002	—0.012	0

TABLE XXII

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT SODIUM ARSENITE (5 P.P.M.–100 P.P.M. As) FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.601±0.006		0.534±0.011	
Glucose	0.721±0.025	0.120	1.309±0.014	0.775
Glucose + 5 p.p.m. As	0.866±0.009	0.265	1.600±0.008	1.066
Glucose + 25 p.p.m. As	0.642±0.000	0.041	3.791±0.032	3.257
Glucose + 100 p.p.m. As	0.485±0.023	—0.116	5.665±0.037	5.132

It is evident that arsenite decreased the conversion of glucose to fructose and the formation of sucrose. One hundred p.p.m. As inhibited these processes 100 per cent.

The effect of arsenite upon the formation of sucrose from fructose is shown in Table XXIII. The gains in sugars and the synthetic efficiencies are recorded in Table XXIV. The percentages of fructose and glucose are reported in Table XXV.

TABLE XXIII

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH FRUCTOSE WITH AND WITHOUT SODIUM ARSENITE (5 P.P.M. As–100 P.P.M. As) FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	74.54±0.081	0.735±0.011	1.541±0.013	2.358±0.002
Fructose	73.59±0.162	1.336±0.013	4.640±0.008	6.221±0.021
Fructose + 5 p.p.m. As	73.53±0.105	1.546±0.023	4.422±0.023	6.200±0.000
Fructose + 25 p.p.m. As	74.08±0.033	2.115±0.019	2.932±0.008	5.202±0.027
Fructose + 100 p.p.m. As ...	72.60±0.091	3.741±0.013	1.506±0.003	5.326±0.009

TABLE XXIV

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH FRUCTOSE WITH AND WITHOUT SODIUM ARSENITE (5 P.P.M.–100 P.P.M. As) FOR 24 HOURS, CALCULATED FROM TABLE XXIII

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Fructose	3.863	3.099	80.22
Fructose + 5 p.p.m. As	3.842	2.881	74.99
Fructose + 25 p.p.m. As	2.844	1.391	48.91
Fructose + 100 p.p.m. As	2.968	—0.025	0

TABLE XXV

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH FRUC-
TOSE WITH AND WITHOUT SODIUM ARSENITE (5 P.P.M.–100 P.P.M. As) FOR
24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.481±0.010		0.254±0.000	
Fructose	1.019±0.050	0.538	0.317±0.037	0.063
Fructose + 5 p.p.m. As	1.053±0.030	0.572	0.492±0.007	0.238
Fructose + 25 p.p.m. As	1.919±0.038	1.438	0.195±0.056	—0.059
Fructose + 100 p.p.m. As	3.861±0.023	3.380	0.000±0.000	—0.254

These results show that arsenic decreases or inhibits the formation of sucrose from
fructose and the conversion of fructose to glucose.

The effect of arsenite upon the formation of sucrose when both glucose and
fructose were supplied to the blades is shown in Table XXVI. The gains in sugars
and the synthetic efficiencies are presented in Table XXVII. The fructose and
glucose percentages are reported in Table XXVIII. The effect of arsenite upon

TABLE XXVI

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH BOTH GLU-
COSE AND FRUCTOSE WITH AND WITHOUT SODIUM ARSENITE (5 P.P.M.–100
P.P.M. As) FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	75.03±0.005	0.980±0.003	1.367±0.017	2.419±0.015
Glucose + fructose	74.19±0.100	1.688±0.009	4.706±0.017	6.642±0.028
Both + 5 p.p.m. As	72.85±0.124	1.714±0.000	4.382±0.006	6.327±0.006
Both + 25 p.p.m. As	72.33±0.043	2.783±0.030	2.493±0.002	5.407±0.028
Both + 100 p.p.m. As	72.97±0.186	4.175±0.005	1.235±0.031	5.475±0.038

TABLE XXVII

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH
BOTH GLUCOSE AND FRUCTOSE WITH AND WITHOUT SODIUM ARSENITE
(5 P.P.M.–100 P.P.M. As) FOR 24 HOURS

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose + fructose	4.226	3.339	79.01
Both + 5 p.p.m. As	3.908	3.015	77.14
Both + 25 p.p.m. As	2.988	1.126	37.68
Both + 100 p.p.m. As	3.056	—0.132	0

TABLE XXVIII

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH BOTH
GLUCOSE AND FRUCTOSE WITH AND WITHOUT SODIUM ARSENITE (5 P.P.M.–
100 P.P.M. As) FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.831±0.059		0.199±0.080	
Glucose + fructose	1.139±0.011	0.308	0.549±0.020	0.350
Both + 5 p.p.m. As	1.166±0.017	0.335	0.548±0.017	0.349
Both + 25 p.p.m. As	1.910±0.030	1.079	0.873±0.000	0.674
Both + 100 p.p.m. As	2.399±0.027	1.568	1.776±0.032	1.577

the formation of sucrose when both glucose and fructose were supplied was very similar to the effect when glucose and fructose were supplied separately. As would be expected, both glucose and fructose accumulated in the presence of arsenite.

The conclusion is drawn that arsenite inhibits both the interconversion of glucose and fructose and the formation of sucrose in blades of the sugar cane plant. The inhibitory effect is found with as little arsenite as 5 p.p.m. Inhibition is complete with 100 p.p.m. As.

8. *Selenite:*

The effect of selenite was reviewed by Elvehjem (23), who said that succinic acid dehydrogenase is almost completely inhibited by selenite; 0.003 M selenite inhibited the oxidation of glucose, mannose, and fructose 80 per cent, of succinate 73 per cent, of acetate 50 per cent, and of lactate and pyruvate less than 10 per cent.

The effect of selenite upon the transformations of sugars was studied with several concentrations of sodium selenite (5–100 p.p.m. Se) and the results are presented in Table XXIX. The gains in sugars and the synthetic efficiencies are reported in Table XXX. The synthetic efficiency of 3.08 obtained with 100 p.p.m. Se was not significant, because the gain in sucrose (0.115) was not significant. The percentages of fructose and glucose are reported in Table XXXI.

TABLE XXIX

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE
WITH AND WITHOUT SODIUM SELENITE (5–100 P.P.M. Se) FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	74.60 ± 0.013	0.785 ± 0.000	1.690 ± 0.006	2.564 ± 0.007
Glucose	73.09 ± 0.043	1.691 ± 0.004	6.137 ± 0.009	8.151 ± 0.005
Glucose + 5 p.p.m. Se .....∴.	72.62 ± 0.071	1.641 ± 0.006	5.797 ± 0.001	7.743 ± 0.004
Glucose + 25 p.p.m. Se	72.75 ± 0.086	2.328 ± 0.012	3.969 ± 0.002	6.506 ± 0.014
Glucose + 100 p.p.m. Se	73.24 ± 0.005	4.389 ± 0.016	1.805 ± 0.027	6.289 ± 0.045

TABLE XXX

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH
GLUCOSE WITH AND WITHOUT SODIUM SELENITE (5–100 P.P.M. Se) FOR 24
HOURS, CALCULATED FROM TABLE XXIX

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	5.587	4.447	79.59
Glucose + 5 p.p.m. Se	5.179	4.107	79.30
Glucose + 25 p.p.m. Se	3.942	2.279	57.81
Glucose + 100 p.p.m. Se	3.725	0.115	3.08

TABLE XXXI

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT SODIUM SELENITE (5 P.P.M.–100 P.P.M. Se) FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.767 ± 0.040		0.049 ± 0.023	
Glucose	1.033 ± 0.069	0.266	0.658 ± 0.077	0.609
Glucose + 5 p.p.m. Se	0.784 ± 0.000	0.017	0.857 ± 0.007	0.808
Glucose + 25 p.p.m. Se	0.832 ± 0.000	0.065	1.496 ± 0.012	1.447
Glucose + 100 p.p.m. Se	0	−0.767	4.389 ± 0.016	4.340

The effect of sodium selenite (100 p.p.m. Se) upon the formation of sucrose from glucose or fructose or both is shown in Table XXXII. The gains in sugars and the synthetic efficiencies are reported in Table XXXIII. The gains in sucrose in the blades supplied with fructose or both glucose and fructose were practically insignificant, which of course made the synthetic efficiencies calculated for those series also of little significance. The percentages of fructose and glucose are recorded in Table XXXIV. Glucose accumulated in the series supplied with glu-

TABLE XXXII

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE OR FRUCTOSE WITH AND WITHOUT SODIUM SELENITE (100 P.P.M. Se) FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	66.04±0.024	0.405±0.000	2.978±0.012	3.540±0.012
Glucose	64.11±0.005	1.087±0.020	5.691±0.035	7.079±0.017
Fructose	61.91±0.005	1.383±0.004	4.800±0.002	6.435±0.001
Both	61.77±0.038	1.166±0.010	4.244±0.018	5.633±0.029
Glucose + 100 p.p.m. Se	64.59±0.014	2.846±0.005	2.787±0.006	5.780±0.000
Fructose + 100 p.p.m. Se	63.27±0.043	2.222±0.019	3.130±0.010	5.517±0.008
Both + 100 p.p.m. Se	61.94±0.110	2.540±0.016	3.254±0.028	5.966±0.014

TABLE XXXIII

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH GLUCOSE OR FRUCTOSE WITH AND WITHOUT SODIUM SELENITE (100 P.P.M. Se) FOR 24 HOURS, CALCULATED FROM TABLE XXXII

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	3.539	2.713	76.66
Fructose	2.895	1.822	62.93
Both	2.093	1.266	60.48
Glucose + Se	2.240	—0.191	0
Fructose + Se	1.977	0.152	7.68
Both + Se	2.426	0.276	11.37

TABLE XXXIV

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE OR FRUCTOSE WITH AND WITHOUT SODIUM SELENITE (100 P.P.M. Se) FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.146±0.029		0.259±0.028	
Glucose	0.193±0.025	0.047	0.894±0.046	0.635
Fructose	0.926±0.025	0.780	0.457±0.021	0.198
Both	0.701±0.021	0.555	0.464±0.031	0.205
Glucose + Se	0.545±0.082	0.399	2.301±0.087	2.042
Fructose + Se	2.060±0.072	1.914	0.177±0.084	—0.082
Both + Se	1.496±0.051	1.350	1.044±0.036	0.785

cose plus selenite, while fructose accumulated in the series supplied with fructose plus selenite.

It is evident that sodium selenite prevented the interconversion of glucose and fructose whichever sugar was supplied. Selenite also prevented the formation of

sucrose whichever sugar was supplied. Some process necessary for synthesis in addition to interconversion of glucose and fructose was also inhibited by selenite, for the synthesis of sucrose was inhibited when both glucose and fructose were supplied.

9. *Effect of arsenite and selenite on photosynthesis and sucrose synthesis:*

A comparison of the effects of arsenite and selenite upon the formation of sucrose in detached blades in the light supplied with water and in the dark supplied with glucose was undertaken, with the results shown in Tables XXXV and XXXVI.

Table XXXV shows that the formation of sucrose was decreased considerably by arsenite and selenite, both in the light and in the dark. Table XXXVI shows that the blades supplied with glucose with arsenite or selenite in the dark accumulated glucose and lost fructose, in agreement with the results presented in Tables XXII, XXV, XXXI, and XXXIV. The blades in water in the light also accumulated glucose but not fructose, when given arsenite or selenite. Since blades known to be supplied with glucose accumulate glucose, and blades known to be supplied with fructose accumulate fructose, in the presence of arsenite or selenite, the results in Table XXXVI constitute strong evidence that the first sugar formed in photosynthesis is glucose alone.

TABLE XXXV

MOISTURE AND SUGAR PERCENTAGES IN BLADES IN THE LIGHT WITH WATER AND IN THE DARK WITH GLUCOSE, WITH AND WITHOUT SODIUM ARSENITE (5–100 P.P.M. As) OR SODIUM SELENITE (5–100 P.P.M. Se) FOR 12 HOURS

Series	Moisture	Reducing sugars	Sucrose	Gain in sucrose	Total sugars
Initial control	71.52±0.057	0.974±0.030	3.552±0.040		4.713±0.011
Water in light	68.11±0.071	1.910±0.017	7.017±0.040	3.465	9.296±0.059
Water + 5 p.p.m. As...	68.40±0.048	1.584±0.020	5.380±0.020	1.828	7.247±0.000
Water + 25 p.p.m. As..	69.31±0.119	1.486±0.009	4.604±0.027	1.052	6.332±0.018
Water + 100 p.p.m. As.	69.59±0.057	1.269±0.042	4.231±0.005	0.679	5.722±0.037
Water + 5 p.p.m. Se...	69.63±0.124	1.503±0.018	5.707±0.021	2.155	7.511±0.004
Water + 25 p.p.m. Se..	68.76±0.057	1.424±0.012	5.785±0.021	2.233	7.514±0.035
Water + 100 p.p.m. Se.	69.48±0.038	1.411±0.007	4.751±0.018	1.199	6.412±0.011
Glucose in dark	70.03±0.052	1.248±0.012	4.453±0.055	0.901	5.935±0.045
Glucose + 5 p.p.m. As..	70.05±0.062	1.342±0.003	4.351±0.006	0.799	5.923±0.010
Glucose + 25 p.p.m. As.	71.15±0.091	1.472±0.003	4.023±0.018	0.471	5.707±0.021
Glucose + 100 p.p.m. As	70.64±0.000	1.588±0.011	3.373±0.000	—0.179	5.139±0.011
Glucose + 5 p.p.m. Se..	69.18±0.029	1.236±0.000	4.610±0.027	1.058	6.089±0.029
Glucose + 25 p.p.m. Se.	68.83±0.100	1.376±0.005	4.322±0.009	0.770	5.926±0.004
Glucose + 100 p.p.m. Se	70.30±0.114	1.690±0.000	3.647±0.004	0.095	5.530±0.006

TABLE XXXVI

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES IN THE LIGHT WITH WA-
TER AND IN THE DARK WITH GLUCOSE, WITH AND WITHOUT SODIUM
ARSENITE (5–100 P.P.M. As) OR SODIUM SELENITE (5–100 P.P.M. Se), FOR 12
HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.798±0.013		0.175±0.043	
Water in light...................	1.445±0.009	0.647	0.465±0.009	0.290
Water + 5 p.p.m. As	0.968±0.024	0.170	0.616±0.044	0.441
Water + 25 p.p.m. As	0.761±0.018	—0.037	0.725±0.028	0.550
Water + 100 p.p.m. As	0.824±0.002	0.026	0.445±0.045	0.270
Water + 5 p.p.m. Se	0.812±0.050	0.014	0.691±0.032	0.516
Water + 25 p.p.m. Se	0.871±0.014	0.073	0.553±0.027	0.378
Water + 100 p.p.m. Se	0.758±0.011	—0.040	0.653±0.019	0.478
Glucose in dark	0.522±0.025	—0.276	0.726±0.012	0.551
Glucose + 5 p.p.m. As	0.596±0.004	—0.202·	0.746±0.000	0.571
Glucose + 25 p.p.m. As	0.574±0.013	—0.224	0.898±0.010	0.723
Glucose + 100 p.p.m. As	0.544±0.016	—0.254	1.044±0.005	0.869
Glucose + 5 p.p.m. Se	0.662±0.039	—0.136	0.574±0.039	0.399
Glucose + 25 p.p.m. Se	0.412±0.011	—0.386	0.964±0.017	0.789
Glucose + 100 p.p.m. Se	0.295±0.014	—0.503	1.395±0.013	1.220

10. Fluoride:

Fluoride exerts a depressing effect upon several steps in respiratory and fermen-
tative processes. The effects of fluoride were summarized by Elvehjem (23), who
stated that fluoride partially inhibits succinic acid dehydrogenase and alphaphospho-
glyserol dehydrogenase. Fluoride also inhibits lactic dehydrogenase but not malic
dehydrogenase. Fluoride inhibits glycolysis chiefly by inhibiting the splitting of
phosphate esters. Sodium fluoride (0.005 M) inhibits the rephosphorylation of
adenylic acid by intermediate products of glycogenolysis. According to MacFar-
lane (55), 0.02 M sodium fluoride is required for 100 per cent inhibition of the
breakdown of phosphoglyceric acid to phosphopyruvic acid. King (46) stated that
the enzymic synthesis of cocarboxylase is inhibited by fluoride. Borei (5) stated
that fluoride had no effect upon cytochrome C or upon cytochrome oxidase. Runn-
ström, Borei, and Sperber (74) reported that fluoride depressed the respiration of
yeast by its effect on an intermediate substance between the dehydrogenase system
and the cytochrome system. This is considered by Szent-Györgyi (79) to be the
point where fumaric, succinic, and oxaloacetic acids enter into the respiratory
scheme. Kalckar (42) found that esterification of glucose with inorganic phos-
phate in cell-free kidney extract occurred under aerobic conditions, and that a mix-
ture of fructose diphosphate and phosphoglyceric acid accumulated in the presence
of sodium fluoride. Case (8) reported that hexokinase is inhibited by M/50 sodium
fluoride (= 0.02 M), while Iri (40) found that 0.01 M fluoride had no effect upon
hexokinase.

Several tests have been conducted to find the effect of various concentrations of
fluoride upon interconversion and synthesis. The results of an experiment using
glucose are presented in Table XXXVII. The gains in sugars and the synthetic
efficiencies are shown in Table XXXVIII. The percentages of fructose and glucose

are reported in Table XXXIX. It is evident that fluoride exerted a depressing effect both upon the conversion of glucose to fructose and upon the formation of sucrose.

TABLE XXXVII
MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT SODIUM FLUORIDE (47 P.P.M. F–380 P.P.M. F) FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	71.74±0.167	0.898±0.011	1.607±0.023	2.590±0.013
Glucose	70.08±0.114	1.387±0.009	5.965±0.048	7.666±0.060
Glucose + 47 p.p.m. F	70.54±0.162	1.477±0.005	5.651±0.004	7.426±0.000
Glucose + 95 p.p.m. F	71.19±0.052	1.693±0.001	4.914±0.002	6.866±0.003
Glucose + 190 p.p.m. F	70.88±0.086	2.745±0.009	4.072±0.003	7.031±0.013
Glucose + 380 p.p.m. F	70.29±0.119	3.931±0.013	3.089	7.212

TABLE XXXVIII
GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT SODIUM FLUORIDE (47 P.P.M.–380 P.P.M. F) FOR 24 HOURS, CALCULATED FROM TABLE XXXVII

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	5.076	4.358	85.85
Glucose + 47 p.p.m. F	4.836	4.044	83.62
Glucose + 95 p.p.m. F	4.276	3.307	77.33
Glucose + 190 p.p.m. F	4.441	2.465	55.50
Glucose + 380 p.p.m. F	4.622	1.482	32.06

TABLE XXXIX
FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT SODIUM FLUORIDE (47 P.P.M.–380 P.P.M. F) FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.589±0.024		0.308±0.035	
Glucose	0.695±0.005	0.106	0.691±0.004	0.383
Glucose + 47 p.p.m. F	0.639±0.018	0.050	0.838±0.013	0.530
Glucose + 95 p.p.m. F	0.562±0.021	—0.027	1.131±0.023	0.823
Glucose + 190 p.p.m. F	0.930±0.046	0.341	1.814±0.056	1.506
Glucose + 380 p.p.m. F	0.564±0.020	—0.025	3.367±0.034	3.059

Another experiment was conducted in which both glucose and fructose were used, and the results are set out in Table XL. The gains in sugars and the synthetic efficiencies are reported in Table XLI. The percentages of fructose and glucose are presented in Table XLII. Fluoride exerted a depressing effect upon the intercon-

TABLE XL
MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE OR FRUCTOSE WITH AND WITHOUT SODIUM FLUORIDE (95 P.P.M. F–380 P.P.M. F) FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	72.43±0.014	0.844±0.002	1.652±0.021	2.583±0.025
Glucose	72.91±0.038	1.076±0.008	3.454±0.012	4.713±0.022
Fructose	72.56±0.043	1.017±0.017	3.527±0.031	4.729±0.050
Both	71.54±0.052	0.883±0.003	3.433±0.046	4.497±0.051
Glucose + 95 p.p.m. F	72.06±0.029	1.225±0.007	2.800±0.013	4.173±0.021
Fructose + 95 p.p.m. F	72.37±0.005	1.379±0.001	2.853±0.007	4.382±0.009
Both + 95 p.p.m. F	71.82±0.029	1.298±0.002	2.944±0.004	4.397±0.006

Glucose + 190 p.p.m. F	**71.87**±0.052	**1.376**±0.014	**2.639**±0.026	**4.155**±0.013
Fructose + 190 p.p.m. F	**71.39**±0.052	**1.486**±0.000	**2.856**±0.002	**4.493**±0.002
Both + 190 p.p.m. F	**71.42**±0.052	**1.562**±0.011	**3.047**±0.031	**4.770**±0.021
Glucose + 380 p.p.m. F	**71.52**±0.000	**2.016**±0.014	**2.781**±0.000	**4.944**±0.015
Fructose + 380 p.p.m. F	**71.78**±0.029	**1.892**±0.004	**2.866**±0.005	**4.909**±0.009
Both + 380 p.p.m. F	**71.58**±0.029	**2.033**±0.008	**2.711**±0.008	**4.887**±0.000

version of glucose and fructose and the formation of sucrose whichever sugar was supplied. The depressing effect was correlated with the amount of fluoride supplied. Since the synthetic efficiency was depressed just as much when both glucose and fructose were supplied as when either alone was given to the blades, fluoride must affect some process necessary for synthesis in addition to its effect upon interconversion of glucose and fructose. However, even 380 p.p.m. F ($= 0.02$ M) did not inhibit synthesis completely.

TABLE XLI

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH GLUCOSE OR FRUCTOSE WITH AND WITHOUT SODIUM FLUORIDE (95 P.P.M.–380 P.P.M. F) FOR 24 HOURS, CALCULATED FROM TABLE XL

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	2.130	1.802	84.60
Fructose	2.146	1.875	87.37
Both	1.914	1.781	93.05
Glucose + 95 p.p.m. F	1.590	1.148	72.20
Fructose + 95 p.p.m. F	1.799	1.201	66.75
Both + 95 p.p.m. F	1.814	1.292	71.22
Glucose + 190 p.p.m. F	1.572	0.987	62.78
Fructose + 190 p.p.m. F	1.910	1.204	63.03
Both + 190 p.p.m. F	2.187	1.395	63.78
Glucose + 380 p.p.m. F	2.361	1.129	47.81
Fructose + 380 p.p.m. F	2.326	1.214	52.19
Both + 380 p.p.m. F	2.304	1.059	45.96

TABLE XLII

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE OR FRUCTOSE WITH AND WITHOUT SODIUM FLUORIDE (95 P.P.M. F–380 P.P.M. F) FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.824±0.006		0.019±0.004	
Glucose	0.592±0.033	—0.232	0.484±0.042	0.465
Fructose	0.921±0.049	0.097	0.096±0.032	0.077
Both	0.437±0.007	—0.387	0.446±0.009	0.427
Glucose + 95 p.p.m. F	0.812±0.022	—0.012	0.413±0.029	0.394
Fructose + 95 p.p.m. F	1.289±0.044	0.465	0.090±0.043	0.071
Both + 95 p.p.m. F	0.849±0.019	0.025	0.449±0.017	0.430
Glucose + 190 p.p.m. F	0.782±0.007	—0.042	0.594±0.007	0.575
Fructose + 190 p.p.m. F	1.346±0.014	0.522	0.140±0.014	0.121
Both + 190 p.p.m. F	0.960±0.041	0.136	0.602±0.029	0.583
Glucose + 380 p.p.m. F	0.614±0.016	—0.210	1.402±0.030	1.383
Fructose + 380 p.p.m. F	1.866±0.022	1.042	0.032±0.015	0.013
Both + 380 p.p.m. F	1.350±0.039	0.526	0.682±0.031	0.663

11. *Malonate:*

Malonate inhibits succinic dehydrogenase, but in the presence of fumaric acid, tissues are insensitive to malonate, according to Oppenheimer (67). Elvehjem (23) stated that malonate inhibits succinic dehydrogenase, lactic dehydrogenase, the oxidation of fatty acids, glucose oxidation by brain, and the oxidation of ethyl alcohol by liver.

A test was conducted to find the effect of malonate with and without fumaric acid upon interconversion and synthesis. The results are presented in Table XLIII. The gains in sugars and the synthetic efficiencies are shown in Table XLIV. The percentages of fructose and glucose are presented in Table XLV. It is true that

TABLE XLIII

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT SODIUM MALONATE (0.5%) AND FUMARIC ACID (0.4%) FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	67.92 ± 0.029	0.338 ± 0.001	2.507 ± 0.013	2.978 ± 0.016
Glucose	65.84 ± 0.029	1.285 ± 0.001	4.818 ± 0.046	6.358 ± 0.047
Glucose + fumaric acid	66.95 ± 0.052	1.272 ± 0.000	3.921 ± 0.027	5.399 ± 0.030
Glucose + malonate	67.26 ± 0.000	0.963 ± 0.017	3.453 ± 0.020	4.599 ± 0.005
Glucose + malonate + fumaric acid	66.08 ± 0.033	1.101 ± 0.000	4.218 ± 0.004	5.541 ± 0.005

TABLE XLIV

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT SODIUM MALONATE (0.5%) AND FUMARIC ACID (0.4%) FOR 24 HOURS, CALCULATED FROM TABLE XLIII

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	3.380	2.311	68.37
Glucose + fumaric acid	2.421	1.414	58.40
Glucose + malonate	1.621	0.946	58.35
Glucose + malonate + fumaric acid .	2.563	1.711	66.75

TABLE XLV

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT SODIUM MALONATE (0.5%) AND FUMARIC ACID (0.4%) FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.374 ± 0.010		0 ± 0.000	
Glucose	0.563 ± 0.031	0.189	0.722 ± 0.030	0.722
Glucose + fumaric acid	0.819 ± 0.051	0.445	0.453 ± 0.050	0.453
Glucose + malonate	0.783 ± 0.049	0.409	0.180 ± 0.066	0.180
Glucose + malonate + fumaric acid	0.483 ± 0.003	0.109	0.618 ± 0.004	0.618

sodium malonate decreased the synthetic efficiency when used alone but not when used with fumaric acid which would be expected if the effect is on succinic dehydrogenase. However, the depressing effect was so little compared with the effects of arsenite, selenite, and fluoride, and considering the comparatively strong concentration of sodium malonate used, that there is no real evidence of inhibition by malonate.

Neither was there any evidence of an inhibitory effect of malonate upon the conversion of glucose to fructose.

12. Acenaphthene:

Shmuck (75) found that acenaphthene interfered with the metabolism of wheat sprouts by reducing respiration, acidifying the sap presumably through the formation of free phosphoric acid from nucleoproteins, and doubling the glucolytic action.

Acenaphthene was dissolved in hot alcohol and diluted with glucose solution, resulting in a milky liquid. An equal amount of alcohol was used in the glucose control. The results of the test are presented in Table XLVI. The gains in sugars and the synthetic efficiencies are reported in Table XLVII. The percentages of fructose and glucose are recorded in Table XLVIII. Acenaphthene appeared to aid both the conversion of glucose to fructose and the formation of sucrose a little.

TABLE XLVI

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT ACENAPHTHENE (0.1%) FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	71.38±0.014	1.088±0.012	2.263±0.003	3.470±0.009
Glucose	70.62±0.052	1.785±0.006	3.952±0.009	5.945±0.003
Glucose + acenaphthene	70.21±0.009	2.012±0.014	4.949±0.019	7.222±0.034

TABLE XLVII

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH GLUCOSE, WITH AND WITHOUT ACENAPHTHENE (0.1%) FOR 24 HOURS, CALCULATED FROM TABLE XLVI

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	2.475	1.689	68.24
Glucose + acenaphthene	3.752	2.686	71.58

TABLE XLVIII

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT ACENAPHTHENE (0.1%) FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.743±0.001		0.345±0.010	
Glucose	0.640±0.019	—0.103	1.145±0.013	0.800
Glucose + acenaphthene	1.333±0.009	0.590	0.679±0.004	0.334

13. Chloroform:

Irving (41) reported that small doses of chloroform increased the intensity of respiration in cherry laurel leaves, medium doses caused an initial increase followed by a decrease to below normal, and strong doses gave a rapid fall to zero. Deleano and Dick (17) found that translocation of material from the leaves of *Vitis vinifera* was not affected by chloroforming the petioles, and that chloroform had no effect upon enzyme activity and starch hydrolysis. Spoehr and Milner (77), however, found that leaves of *Helianthus annuus* and *Nicotiana Tabacum* when killed by means of chloroform retained their amylase but showed no starch dissolution even after 143 days, and suggested that the treatment with chloroform resulted in marked

changes in the finer structure of the cell and in colloidal phase relationships of the components of the chloroplasts and the surrounding protoplasm.

Blades of sugar cane were placed under a bell jar with chloroform for two hours. For the first hour the chloroform was in a beaker, but for the second hour cotton soaked in chloroform was used. The leaves did not become flaccid but they did become very cold. After the two hours' exposure to chloroform, the leaves were supplied with glucose for 24 hours. The results are set out in Table XLIX. The gains in sugars and the synthetic efficiencies are presented in Table L. The percentages of fructose and glucose are reported in Table LI. The treatment with chloroform decreased the synthetic efficiency considerably, but did not inhibit synthesis entirely. The conversion of glucose to fructose was also diminished by the treatment with chloroform.

TABLE XLIX

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE FOR 24 HOURS, WITH AND WITHOUT PREVIOUS EXPOSURE TO CHLOROFORM FOR 2 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	66.06 ± 0.024	0.550 ± 0.002	1.802 ± 0.008	2.447 ± 0.007
Glucose	67.23 ± 0.105	2.070 ± 0.034	5.546 ± 0.017	7.909 ± 0.003
Chloroform-glucose	67.74 ± 0.000	2.941 ± 0.015	3.862 ± 0.012	7.006 ± 0.027

TABLE L

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH GLUCOSE FOR 24 HOURS, WITH AND WITHOUT PREVIOUS EXPOSURE TO CHLOROFORM FOR 2 HOURS, CALCULATED FROM TABLE XLIX

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	5.462	3.744	68.54
Chloroform-glucose	4.559	2.060	45.18

TABLE LI

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE FOR 24 HOURS, WITH AND WITHOUT PREVIOUS EXPOSURE TO CHLOROFORM FOR 2 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.672 ± 0.023		$0 \quad \pm 0.000$	
Glucose	0.737 ± 0.029	0.065	1.334 ± 0.008	1.334
Chloroform–glucose	0.689 ± 0.023	0.017	2.251 ± 0.038	2.251

14. Dinitrophenol:

Norris (64) reported that 2:4–dinitrophenol caused an increase in oxygen consumption. du Buy and Olson (21) found that dinitrophenol (50 p.p.m. for 30 minutes) markedly inhibited the respiration of Avena coleoptile, and that respiration was completely stopped by 100 p.p.m. for 30 minutes. Oppenheimer (67) stated that dinitrophenol increased the rate of oxidation in animals and plants, and that while it increased both respiration and glucolysis, the main effect was a stimulation of anaerobic sugar breakdown.

The effect of dinitrophenol upon the transformations of sugars was studied, using 5, 50, and 100 p.p.m. The results for moisture and sugars are recorded in Table

LII. The gains in sugars and the synthetic efficiencies are reported in Table LIII. Dinitrophenol appeared to diminish synthesis a little, in the higher concentrations.

TABLE LII

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT 2:4-DINITROPHENOL (5 P.P.M.–100 P.P.M.) FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	68.23±0.095	0.752±0.028	2.277±0.003	3.150±0.025
Glucose	68.58±0.009	1.273±0.019	4.835±0.030	6.363±0.050
Glucose + 5 p.p.m. DNP	68.83±0.028	1.209±0.006	4.655±0.005	6.110±0.000
Glucose + 50 p.p.m. DNP ...	69.70±0.019	1.413±0.008	4.584±0.041	6.239±0.035
Glucose + 100 p.p.m. DNP ..	69.00±0.133	1.504±0.012	4.686±0.018	6.437±0.030

TABLE LIII

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT 2:4-DINITROPHENOL (5 P.P.M.–100 P.P.M.) FOR 24 HOURS, CALCULATED FROM TABLE LII

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	3.213	2.558	79.61
Glucose + 5 p.p.m. DNP	2.960	2.378	80.33
Glucose + 50 p.p.m. DNP	3.089	2.307	74.68
Glucose + 100 p.p.m. DNP	3.287	2.409	73.28

15. Ethyl alcohol:

Elvehjem stated that ethyl alcohol completely stopped the reduction of cytochrome.

The effect of 2 per cent ethyl alcohol upon synthesis is shown in Tables LIV and LV. The effect of 5 per cent ethyl alcohol was then studied, with the results reported in Tables LVI and LVII. In both of these tests ethyl alcohol appeared to raise the synthetic efficiency a little.

TABLE LIV

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT 2% ETHYL ALCOHOL FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	73.07±0.033	0.827±0.002	2.301±0.022	3.250±0.025
Glucose	72.59	2.105±0.002	7.282±0.014	9.771±0.012
Glucose + alcohol	71.79±0.076	1.850±0.011	7.380±0.001	9.619±0.009

TABLE LV

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT 2% ETHYL ALCOHOL FOR 24 HOURS, CALCULATED FROM TABLE LIV

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	6.521	4.981	76.38
Glucose + alcohol	6.369	5.079	79.74

TABLE LVI

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE
WITH AND WITHOUT 5% ETHYL ALCOHOL FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	71.39 ± 0.019	1.495 ± 0.009	3.047 ± 0.005	4.703 ± 0.003
Water	73.08 ± 0.048	1.683 ± 0.013	2.412 ± 0.009	4.222 ± 0.023
Alcohol	72.30 ± 0.033	1.254 ± 0.006	2.345 ± 0.018	3.723 ± 0.026
Glucose	72.01 ± 0.052	1.960 ± 0.013	4.894 ± 0.022	7.112 ± 0.010
Glucose + alcohol	71.35 ± 0.095	1.970 ± 0.003	5.078 ± 0.017	7.310 ± 0.019

TABLE LVII

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH
GLUCOSE WITH AND WITHOUT 5% ETHYL ALCOHOL FOR 24 HOURS, CALCU-
LATED FROM TABLE LV

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Water	-0.481	-0.635	
Alcohol	-0.980	-0.702	
Glucose	2.409	1.847	76.67
Glucose + alcohol	2.607	2.031	77.90

16. Histidine:

Norris (64) reported that histidine, in 6×10^{-7} molar concentration, reduced respiration.

The effect of histidine upon synthesis is shown in Tables LVIII and LVIX. The fructose and glucose percentages are presented in Table LX. Histidine ap-

TABLE LVIII

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE
WITH AND WITHOUT HISTIDINE FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	68.21 ± 0.076	0.815 ± 0.003	2.151 ± 0.003	3.080 ± 0.007
Glucose	69.98 ± 0.024	1.330 ± 0.006	4.659 ± 0.008	6.234 ± 0.003
Glucose + histidine 6×10^{-7}M	69.65 ± 0.009	1.243 ± 0.007	4.548 ± 0.000	6.031 ± 0.008
Glucose + histidine 6×10^{-6}M	70.07 ± 0.067	1.269 ± 0.002	4.738 ± 0.000	6.256 ± 0.003
Glucose + histidine 6×10^{-5}M	68.55 ± 0.086	1.165 ± 0.007	4.726 ± 0.008	6.141 ± 0.016
Glucose + histidine 6×10^{-4}M	67.63 ± 0.043	0.957 ± 0.004	4.095 ± 0.005	5.268 ± 0.000

TABLE LIX

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH
GLUCOSE WITH AND WITHOUT HISTIDINE FOR 24 HOURS, CALCULATED
FROM TABLE LVIII

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	3.154	2.508	79.51
Glucose + histidine 6×10^{-7}M........	2.951	2.397	81.22
Glucose + histidine 6×10^{-6}M........	3.176	2.587	81.45
Glucose + histidine 6×10^{-5}M........	3.061	2.575	84.12
Glucose + histidine 6×10^{-4}M........	2.188	1.944	88.84

<div align="center">TABLE LX</div>

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT HISTIDINE FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.459±0.011		0.356±0.014	
Glucose	0.921±0.031	0.462	0.409±0.037	0.053
Glucose + histidine 6x10^{-7}M	0.919±0.034	0.460	0.324±0.041	—0.032
Glucose + histidine 6x10^{-6}M	0.831±0.045	0.372	0.437±0.043	0.081
Glucose + histidine 6x10^{-5}M	0.891±0.041	0.432	0.274±0.049	—0.082
Glucose + histidine 6x10^{-4}M	0.934±0.014	0.475	0.030±0.014	—0.326

peared to increase synthesis a little, particularly in 6x10^{-4} M concentration. There was no apparent effect upon the conversion of glucose to fructose.

17. Phloridzin:

According to Elvehjem, 0.005–0.2 M phloridzin inhibited phosphorylation and dephosphorylation in yeast and muscle. It also inhibited the formation of lactic acid from glucose or glycogen. 0.01 M phloridzin inhibited the dismutation of triose phosphate to phosphoglyceric and glycerophosphoric acids in muscle. In dried yeast, phloridzin almost completely inhibited the formation of adenosine triphosphate from adenosine phosphate and fructose diphosphate. Ostern, Baranowski and Terszakowec' (68) reported that phloridzin, 7x10^{-3} M, gave 100 per cent inhibition of adenosine phosphorylase. Dahl (14) found that phloridzin hindered the phosphorylation of starch and glycogen in muscle extract. Cori and Cori (12) state that phloridzin inhibited the action of phosphorylase, which catalyzes the reaction glycogen + inorganic phosphate $\rightleftarrows$ glucose–1–phosphate, in both directions. Lisitsyn (54) found that 0.005 M phloridzin inhibited the synthesis of sucrose in the leaves of *Arctium lappa* and *Crataegus* sp. but not in the leaves of *Tussilago farfara*.

The effect of phloridzin upon sugar transformations is shown in Table LXI. The gains in sugars and the synthetic efficiencies are reported in Table LXII. The percentages of fructose and glucose are recorded in Table LXIII. Phloridzin did not inhibit either the interconversion of glucose and fructose or the synthesis of sucrose.

<div align="center">TABLE LXI</div>

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE OR FRUCTOSE WITH AND WITHOUT PHLORIDZIN (0.01 M) FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	71.44±0.033	0.902±0.001	2.293±0.000	3.316±0.000
Glucose	71.04±0.067	1.225±0.004	4.771±0.016	6.247±0.020
Fructose	72.24±0.019	1.395±0.003	4.656±0.000	6.297±0.004
Both	71.91±0.019	1.283±0.048	4.748±0.021	6.281±0.027
Glucose + phloridzin	71.56±0.038	1.135±0.004	4.440±0.000	5.854±0.017
Fructose + phloridzin	71.79±0.009	1.418±0.009	4.381±0.014	6.030±0.005
Both + phloridzin	71.33±0.043	1.168±0.012	4.405±0.033	5.805±0.022

TABLE LXII

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH
GLUCOSE OR FRUCTOSE WITH AND WITHOUT PHLORIDZIN (0.01 M) FOR 24
HOURS, CALCULATED FROM TABLE LXI

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	2.931	2.478	84.54
Fructose	2.981	2.363	79.26
Both	2.965	2.455	82.79
Glucose + phloridzin	2.538	2.147	84.59
Fructose + phloridzin	2.714	2.088	76.93
Both + phloridzin	2.489	2.112	84.85

TABLE LXIII

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLU-
COSE OR FRUCTOSE WITH AND WITHOUT PHLORIDZIN (0.01 M) FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.512 ± 0.016		0.390 ± 0.017	
Glucose	0.648 ± 0.021	0.136	0.576 ± 0.025	0.186
Fructose	1.289 ± 0.009	0.777	0.106 ± 0.013	-0.284
Both	1.136 ± 0.015	0.624	0.147 ± 0.019	-0.243
Glucose + phloridzin	0.667 ± 0.031	0.155	0.468 ± 0.027	0.078
Fructose + phloridzin	1.190 ± 0.026	0.678	0.228 ± 0.035	-0.162
Both + phloridzin	1.015 ± 0.004	0.503	0.153 ± 0.017	-0.237

18. Quinine:

Enders and Wieninger (24) reported that quinine and several other alkaloids
inhibited growth and fermentation by yeast. Fermentation was inhibited by lower
concentrations than were required to inhibit multiplication.

The effect of quinine (0.01%) upon the formation of sucrose was tried in two
tests. In the first test the synthetic efficiencies were as follows: with glucose 86.56;
with glucose + quinine, 93.87. In the second test the synthetic efficiencies were as
follows: with glucose, 82.04; with glucose + quinine, 82.20; with fructose, 78.40;
with fructose + quinine, 87.95; with glucose and fructose, 89.94; with glucose and
fructose + quinine, 89.09. It is evident that the effect of quinine needs further
study before drawing any conclusion.

19. Urethane:

Elvehjem stated that urethane completely stopped the reduction of cytochrome.
It partially inhibited alpha-phosphoglycerol dehydrogenase. In brain, urethane was
found to inhibit the oxidation of glucose, lactate, and pyruvate but not of succinate.
Kempner (45) stated that if a respiratory process is not affected by narcotics, that
process is not bound to cellular structure. Burris and Wilson (7) stated that ure-
thane, like other indifferent narcotics, is considered to be a general inhibitor of dehy-
drogenases and to exert its action by being adsorbed on enzyme surfaces.

Urethane was used in a single test with blades of sugar cane supplied with glu-
cose, with the results presented in Table LXIV. The gains in sugars and the syn-
thetic efficiencies are recorded in Table LXV. The percentages of fructose and glu-

TABLE LXIV

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE
WITH AND WITHOUT URETHANE (1%) FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	69.26±0.048	0.719±0.001	2.669±0.008	3.528±0.009
Glucose	69.39±0.029	1.438±0.030	6.259±0.009	8.027±0.040
Glucose + urethane	68.56±0.129	1.342±0.003	5.794±0.018	7.441±0.015

TABLE LXV

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH
GLUCOSE WITH AND WITHOUT URETHANE (1%) FOR 24 HOURS, CALCU-
LATED FROM TABLE LXIV

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	4.499	3.590	79.79
Glucose + urethane	3.913	3.125	79.86

cose are reported in Table LXVI. Urethane appeared to decrease the absorption of
sugar a little, as shown by the effect on the gain in total sugars. There was no effect
upon synthesis or upon the conversion of glucose to fructose.

TABLE LXVI

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLU-
COSE WITH AND WITHOUT URETHAN (1%) FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.279±0.045		0.440±0.043	
Glucose	0.796±0.020	0.517	0.642±0.009	0.202
Glucose + urethane	0.714±0.019	0.435	0.628±0.016	0.188

20. Brilliant alizarine blue and rosinduline GG:

Michaelis and Smythe (61) studied the effects of several dyes upon fermenta-
tion in yeast, and reported that some dyes prevented the enzymatic conversion of
fructose monophosphate to fructose diphosphate. The dyes with the strongest in-
hibitory effect were brilliant alizarine blue and rosinduline GG. The concentra-
tion employed was 4.9×10^{-3} M. These dyes were used by Smythe (76) for the
quantitative production of the hexose monophosphates.

Experiments have been conducted with both of these dyes to find their effects
upon interconversion and synthesis in the sugar cane plant. The results of a test
with brilliant alizarine blue are presented in Table LXVII. The gains in sugars
and the synthetic efficiencies are recorded in Table LXVIII. The percentages of

TABLE LXVII

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE
OR FRUCTOSE WITH AND WITHOUT BRILLIANT ALIZARINE BLUE (4.9×10^{-3} M)
FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	65.90±0.119	0.431±0.001	2.653±0.005	3.224±0.004
Glucose	66.19±0.000	1.489±0.004	5.149±0.030	6.910±0.028
Fructose	65.45±0.024	1.134±0.013	4.644±0.041	6.022±0.029
Glucose + BAB	61.26±0.076	1.077±0.005	2.866±0.013	4.094±0.019
Fructose + BAB	57.17±0.024	1.214±0.122	2.526±0.023	3.874±0.097

TABLE LXVIII

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH
GLUCOSE OR FRUCTOSE WITH AND WITHOUT BRILLIANT ALIZARINE BLUE
(4.9x10⁻³ M) FOR 24 HOURS, CALCULATED FROM TABLE LXVII

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	3.686	2.496	67.71
Fructose	2.798	1.991	71.15
Glucose + BAB	0.870	0.213	24.48
Fructose + BAB	0.650	—0.127	0

fructose and glucose are reported in Table LXIX. Brilliant alizarine blue decreased the absorption of sugar and inhibited the synthesis of sucrose, but did not inhibit the conversion of fructose to glucose, although it may have decreased the conversion of glucose to fructose. In another test with the same concentration of brilliant alizarine blue, the synthetic efficiencies were as follows: glucose, 68.25; glucose + BAB, 0; fructose, 61.07; fructose + BAB, 17.26. The dye inhibited the formation of sucrose from either glucose or fructose.

TABLE LXIX

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLU-
COSE OR FRUCTOSE WITH AND WITHOUT BRILLIANT ALIZARINE BLUE
(4.9x10⁻³ M) FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.426±0.000		0.005±0.002	
Glucose	0.418±0.009	—0.008	1.071±0.013	1.066
Fructose	0.743±0.039	0.317	0.390±0.026	0.385
Glucose + BAB	0.440±0.048	0.014	0.637±0.053	0.632
Fructose + BAB	0.456±0.024	0.030	0.758±0.098	0.753

Rosinduline GG was used in one test with sugar cane. The concentration used by Michaelis and Smythe was 5x10⁻³ M. I could not find the formula or the molecular weight of rosinduline GG; the concentration used was 1.87 grams per liter. The results are set out in Table LXX. The gains in sugars and the synthetic efficiencies are reported in Table LXXI. The percentages of fructose and glucose are recorded in Table LXXII. The formation of sucrose was cut in half by the use

TABLE LXX

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE
OR FRUCTOSE WITH AND WITHOUT ROSINDULINE GG (1.87 GM.) FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	65.94±0.043	0.787±0.007	4.172±0.003	5.179±0.010
Glucose	66.69±0.014	0.995±0.020	6.585±0.049	7.926±0.031
Fructose	66.05±0.081	1.132±0.022	7.160±0.027	8.669±0.006
Both	68.21±0.013	1.302±0.025	6.973±0.030	8.642±0.006
Glucose + ros. GG	63.47±0.071	2.075±0.009	5.063±0.000	7.405±0.009
Fructose + ros. GG	63.95±0.005	2.104±0.115	4.890±0.208	7.251±0.334
Both + ros. GG	62.43±0.057	1.920±0.028	5.626±0.027	7.842±0.000

TABLE LXXI

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH
GLUCOSE OR FRUCTOSE WITH AND WITHOUT ROSINDULINE GG (1.87 GM/1)
FOR 24 HOURS, CALCULATED FROM TABLE LXX

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	2.747	2.413	87.84
Fructose	3.490	2.988	85.61
Both	3.463	2.801	80.88
Glucose + ros. GG	2.226	0.891	40.02
Fructose + ros. GG	2.072	0.718	34.65
Both + ros. GG	2.663	1.454	54.60

TABLE LXXII

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLU-
COSE OR FRUCTOSE WITH AND WITHOUT ROSINDULINE GG (1.87 GM/1) FOR
24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.658±0.043		0.129±0.050	
Glucose	0.778±0.005	0.120	0.216±0.026	0.087
Fructose	1.112±0.029	0.454	0.064±0.030	−0.065
Both	1.432±0.021	0.774	0.000±0.000	−0.129
Glucose + ros. GG	0.734±0.084	0.076	1.341±0.074	1.212
Fructose + ros. GG	1.052±0.053	0.394	1.051±0.061	0.922
Both + ros. GG	0.965±0.029	0.307	0.954±0.000	0.825

of rosinduline GG. More glucose than fructose accumulated whichever sugar was supplied, which indicates that the dye had no deleterious effect upon the conversion of fructose to glucose, but may have decreased the conversion of glucose to fructose.

Since brilliant alizarine blue and rosinduline GG inhibit the formation of fructose diphosphate from fructose monophosphate, according to Michaelis and Smythe, and since these dyes decreased or inhibited the formation of sucrose from glucose, we may conclude either that the dyes exert a specific effect upon synthesis or that the phosphorylation of glucose or fructose must proceed to the fructose diphosphate stage for the synthesis of sucrose to take place.

21. Iodine, silver nitrate, and copper sulphate:

Herbert (37) found that M/50,000 iodine, silver nitrate, or copper sulphate gave 100 per cent inhibition of zymohexase activity in rabbit skeletal muscle. Zymohexase is the enzyme which catalyzes the breakdown of fructose diphosphate forming dihydroxyacetone phosphate and glyceraldehyde phosphate, or triose phosphate. It is found in plants as well as in animals, as Allen (1) stated that the potato contains zymohexase similar to that in muscle. Rapkine (73) reported that triose phosphate dehydrogenase of muscle is inactivated by iodine.

The studies with brilliant alizarine blue and rosinduline GG reported in this paper led to the conclusion that phosphorylation of glucose or fructose must proceed to the fructose diphosphate stage in order for the synthesis of sucrose to take place. The tests with iodoacetate indicated that phosphorylation does not need to proceed beyond the triose phosphate stage for the synthesis of sucrose to occur. To determine whether fructose diphosphate or triose phosphate is the necessary intermediate

for the formation of sucrose, a test was conducted using iodine, silver nitrate, and copper sulphate in the same concentration used by Herbert. If these chemicals should inhibit synthesis then triose phosphate may be the required substrate rather than fructose diphosphate.

The results for moisture and sugars, obtained in the test with iodine, copper sulphate, and silver nitrate, are presented in Table LXXIII. The gains in sugars and the synthetic efficiencies are reported in Table LXXIV. The percentages of fructose and glucose are recorded in Table LXXV.

TABLE LXXIII

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT I_2, $AgNO_3$, OR $CuSO_4$ (M/50,000) FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	63.20 ± 0.067	0.726 ± 0.005	3.148 ± 0.014	4.040 ± 0.020
Glucose	63.28 ± 0.019	1.186 ± 0.036	5.429 ± 0.017	6.901 ± 0.018
Glucose $+ I_2$	63.55 ± 0.091	1.201 ± 0.000	6.134 ± 0.012	7.658 ± 0.013
Glucose $+ AgNO_3$	63.54 ± 0.129	1.073 ± 0.003	5.611 ± 0.028	6.980 ± 0.032
Glucose $+ CuSO_4$	62.95 ± 0.033	1.106 ± 0.004	6.234 ± 0.006	7.668 ± 0.010

TABLE LXXIV

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT I_2, $AgNO_3$, OR $CuSO_4$ (M/50,000) FOR 24 HOURS, CALCULATED FROM TABLE LXXIII

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	2.861	2.281	79.72
Glucose $+ I_2$	3.618	2.986	82.53
Glucose $+ AgNO_3$	2.940	2.463	83.77
Glucose $+ CuSO_4$	3.628	3.086	85.06

Far from exerting a depressing effect, iodine, silver nitrate, and copper sulphate all increased the synthetic efficiency, according to Table LXXIV. Neither iodine nor copper sulphate affected the conversion of glucose to fructose significantly, but the effect of silver nitrate in depressing the conversion of glucose to fructose may

TABLE LXXV

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT I_2, $AgNO_3$, OR $CuSO_4$ (M/50,000) FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.484 ± 0.013		0.242 ± 0.019	
Glucose	0.608 ± 0.011	0.124	0.578 ± 0.047	0.336
Glucose $+ I_2$	0.678 ± 0.022	0.194	0.523 ± 0.020	0.281
Glucose $+ AgNO_3$	0.102 ± 0.001	-0.382	0.971 ± 0.001	0.729
Glucose $+ CuSO_4$	0.402 ± 0.035	-0.082	0.704 ± 0.039	0.462

have been significant. Since inhibiting the breakdown of fructose diphosphate by zymohexase resulted in an increased synthesis of sucrose, the theory is suggested that fructose diphosphate is a necessary stepping stone in the formation of sucrose from glucose.

22. Sodium diethyldithiocarbamate:

Keilin and Hartree (44) found that sodium diethyldithiocarbamate inhibits succinic dehydrogenase one hundred per cent in 2×10^{-5} M concentration. This concen-

tration was used in a test with blades supplied with glucose for 24 hours. The synthetic efficiency in the series with glucose was 78.64, and in the series with glucose plus sodium diethyldithiocarbamate the synthetic efficiency was 75.80.

Since synthesis was depressed so little by the carbamate, this may indicate that succinic dehydrogenase does not take part in the synthesis of sucrose.

23. *Potassium ferricyanide:*

Mendel and Strelitz (59) reported that potassium ferricyanide increased the Pasteur effect, using 10^{-2} mol./liter. Potassium ferricyanide is a mild oxidizing agent.

One test was conducted in which blades were supplied with potassium ferricyanide along with glucose, the results of which are recorded in Table LXXVI. The

TABLE LXXVI

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT POTASSIUM FERRICYANIDE (3.292 GM/1) FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	67.59±0.033	0.694±0.000	2.675±0.011	3.510±0.012
Glucose	64.10±0.014	3.106±0.016	6.793±0.009	10.257±0.006
Glucose + ferricyanide	63.38±0.038	4.765±0.003	5.141±0.029	10.177±0.028

gains in sugars and the synthetic efficiencies are reported in Table LXXVII. The percentages of fructose and glucose are set out in Table LXXVIII. Potassium ferricyanide considerably decreased the synthetic efficiency and caused an accumulation of glucose but not fructose, which indicates that it interfered with the conversion of glucose to fructose and with the synthesis of sucrose.

TABLE LXXVII

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT POTASSIUM FERRICYANIDE (3.292 GM/1) FOR 24 HOURS, CALCULATED FROM TABLE LXXVI

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	6.747	4.118	61.03
Glucose + K ferricyanide	6.667	2.466	36.98

TABLE LXXVIII

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE WITH AND WITHOUT POTASSIUM FERRICYANIDE (3.292 GM/1) FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.230±0.006		0.464±0.006	
Glucose	0.710±0.040	0.480	2.395±0.057	1.931
Glucose + K ferricyanide	0.730±0.011	0.500	4.034±0.014	3.570

24. *Thymol:*

Thymol, a common antiseptic, was used in one test, the results of which are presented in Table LXXIX. The gains in sugars and synthetic efficiencies are recorded

TABLE LXXIX

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE
WITH AND WITHOUT THYMOL (3 GM/1) FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	71.95±0.062	1.094±0.018	3.548±0.006	4.830±0.011
Glucose	72.13±0.033	1.655±0.011	5.554±0.000	7.502±0.010
Glucose + thymol	71.89±0.071	2.188±0.018	4.788±0.019	7.229±0.039

in Table LXXX, and the percentages of fructose and glucose in Table LXXXI.
Table LXXX shows that thymol decreased the synthetic efficiency from 74.51 to
51.68. Table LXXXI shows that thymol increased the gain in glucose and de-
creased the gain in fructose, indicating that thymol interfered with the conversion
of glucose to fructose.

TABLE LXXX

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH
GLUCOSE WITH AND WITHOUT THYMOL (3 GM/1) FOR 24 HOURS, CALCU-
LATED FROM TABLE LXXIX

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	2.692	2.006	74.51
Glucose + thymol	2.399	1.240	51.68

TABLE LXXXI

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLU-
COSE WITH AND WITHOUT THYMOL (3 GM/1) FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.447±0.023		0.647±0.027	
Glucose	1.217±0.008	0.770	0.438±0.004	−0.209
Glucose + thymol	0.766±0.044	0.319	1.422±0.026	0.775

25. *Sodium chlorate and sodium pentachlorophenate:*

The effect of these chemicals upon synthesis was studied because they are com-
monly used as a weed killer. Sodium chlorate is readily absorbed by leaves or roots
and is translocated in the xylem, killing the tissues. The exact mechanism of kill-
ing is not known. Crafts (13) stated that its effect may be due to its high oxidizing
potential, to the presence of pentavalent chlorine, or to complete oxidation of res-
piratory chromogens. Hance (28) reported that chlorate liberates free or nascent
oxygen, which supposedly destroys weed tissues. Gay (26) studied the effects of
the H.S.P.A. Activator (sodium pentachlorophenate), and found that it promotes
faster and deeper penetration of toxic chemicals into plants; it competes with the
plant for carbon dioxide and oxygen, it decreases transpiration, and it destroys the
enzyme diastase.

For the synthesis test, 0.2 per cent pentachlorophenate and 0.22 per cent chlorate
were used. These weak concentrations were chosen so as not to kill the blades but
to produce partially toxic conditions. The blades given pentachlorophenate were
streaked with red along the veins and midrib for the lower third of the blade, while
the blades given chlorate exhibited no discoloration. The results are recorded in
Table LXXXII. The gains in sugars and the synthetic efficiencies are presented in
Table LXXXIII, and the percentages of fructose and glucose in Table LXXXIV.

TABLE LXXXII

MOISTURE AND SUGAR PERCENTAGES IN BLADES SUPPLIED WITH GLUCOSE
WITH AND WITHOUT SODIUM PENTACHLOROPHENATE (0.2%) AND SODIUM
CHLORATE (0.22%) FOR 24 HOURS

Series	Moisture	Reducing sugars	Sucrose	Total sugars
Initial control	67.11±0.024	0.500±0.003	2.333±0.005	2.956±0.002
Glucose	64.57±0.029	1.531±0.003	5.439±0.008	7.256±0.011
Glucose + Na pentachloro-				
phenate	65.79±0.024	2.070±0.019	3.991±0.019	6.271±0.039
Glucose + Na chlorate	64.31±0.033	1.467±0.019	4.558±0.032	6.264±0.014

TABLE LXXXIII

GAINS IN SUGARS AND SYNTHETIC EFFICIENCY OF BLADES SUPPLIED WITH
GLUCOSE WITH AND WITHOUT SODIUM PENTACHLOROPHENATE (0.2%)
AND SODIUM CHLORATE (0.22%) FOR 24 HOURS, CALCULATED FROM TABLE
LXXXII

Series	Gain in total sugars	Gain in sucrose	Synthetic efficiency
Glucose	4.300	3.106	72.23
Glucose + Na pentachlorophenate ...	3.315	1.658	50.01
Glucose + Na chlorate	3.308	2.225	67.26

TABLE LXXXIV

FRUCTOSE AND GLUCOSE PERCENTAGES IN BLADES SUPPLIED WITH GLU-
COSE WITH AND WITHOUT SODIUM PENTACHLOROPHENATE (0.2%) AND
SODIUM CHLORATE (0.22%) FOR 24 HOURS

Series	Fructose	Gain in fructose	Glucose	Gain in glucose
Initial control	0.568±0.009		0.000±0.000	
Glucose	0.848±0.005	0.280	0.683±0.002	0.683
Glucose + Na pentachlorophenate ..	0.681±0.003	0.113	1.388±0.016	1.388
Glucose + Na chlorate	0.634±0.014	0.066	0.832±0.005	0.832

Both chemicals decreased the absorption of glucose as shown by the gains in total
sugars. The pentachlorophenate decreased the synthetic efficiency and increased the
gain in glucose more than the chlorate did. These findings indicate that both chem-
icals interfered with the conversion of glucose to fructose and with the synthesis of
sucrose, and that the effect of pentachlorophenate was worse than that of the
chlorate.

SUMMARY

The effects of the following inhibitory agents upon the interconversion of glu-
cose and fructose and the formation of sucrose in detached blades of the sugar cane
plant are reported herein: cyanide, pyrophosphate, azide, 8–hydroxyquinoline,
iodoacetic acid, arsenite, selenite, fluoride, malonate, acenaphthene, chloroform,
dinitrophenol, ethyl alcohol, histidine, phloridzin, quinine, urethane, brilliant aliza-
rine blue, rosinduline GG, iodine, silver nitrate, copper sulphate, sodium diethyl-
dithiocarbamate, potassium ferricyanide, thymol, sodium pentachlorophenate, and
sodium chlorate.

Sodium cyanide (0.049 gms/liter) did not inhibit either interconversion or syn-
thesis.

Sodium pyrophosphate (8 gm/liter) did not inhibit either interconversion or synthesis.

Sodium azide (0.05 gm/liter) did not inhibit either interconversion or synthesis, but did decrease the synthetic efficiency from 84 to 78.

8–hydroxyquinoline did not inhibit either interconversion or synthesis.

Since some of the more important inhibitors of iron-catalyzed reactions and copper-catalyzed reactions did not inhibit synthesis, it would seem that the oxidases, peroxidases, catalase, and other enzymes containing iron or copper are not involved in the synthesis of sucrose.

Iodoacetate (0.0001 M) did not inhibit either interconversion or synthesis, whereas a strong concentration (0.01 M) completely inhibited both interconversion and synthesis. This would indicate that the processes of fermentation beginning with triose phosphate dehydrogenase are not involved in the synthesis of sucrose. Some process which is inhibited by 0.01 M iodoacetate is essential for synthesis. This process may be the phosphorylation of glucose by hexokinase.

Sodium arsenite (100 p.p.m. As) completely inhibited both interconversion and synthesis.

Sodium selenite (100 p.p.m. Se) completely inhibited both interconversion and synthesis.

Detached blades supplied with water in the light accumulated glucose but not fructose, when given either arsenite or selenite. Since blades known to be supplied with glucose accumulate glucose, and blades known to be supplied with fructose accumulate fructose, in the presence of arsenite or selenite, the results obtained with blades in water in the light in the presence of these poisons, constitute strong evidence that the first sugar formed in photosynthesis is glucose alone.

Sodium fluoride (47 p.p.m.–380 p.p.m. F) depressed both interconversion and synthesis. The effect of fluoride was not as bad as that of iodoacetate, arsenite, or selenite, since even 380 p.p.m. F ($= 0.02$ M) did not inhibit synthesis completely.

Sodium malonate (0.5%) did not inhibit either interconversion or synthesis, but did decrease the synthetic efficiency from 68 to 58.

Acenaphthene (0.1%) appeared to aid both the conversion of glucose to fructose and the formation of sucrose.

Chloroform decreased both the conversion of glucose to fructose and the synthesis of sucrose.

Dinitrophenol (50–100 p.p.m.) appeared to diminish synthesis a little.

Ethyl alcohol (2–5%) appeared to raise the synthetic efficiency a little.

Histidine appeared to increase synthesis a little, particularly in 6×10^{-4} M concentration.

Phloridzin (0.01 M) had no effect upon either interconversion or synthesis.

Urethane (1%) had no effect upon either interconversion or synthesis.

Brilliant alizarine blue (4.9×10^{-3} M) inhibited synthesis. More glucose than fructose accumulated whichever sugar was supplied, indicating that brilliant alizarine blue did not inhibit the conversion of fructose to glucose but may have decreased the conversion of glucose to fructose.

Rosinduline GG (1.87 gm/liter) cut the synthesis of sucrose in half. More glucose than fructose accumulated whichever sugar was supplied, which indicates that

the dye had no deleterious effect upon the conversion of fructose to glucose but may have decreased the conversion of glucose to fructose.

Since dyes which are known to inhibit the conversion of hexose monophosphate to fructose diphosphate, have been found to prevent the formation of sucrose, it is concluded either that the dyes exert a specific effect upon synthesis or that phosphorylation of glucose must proceed as far as the fructose diphosphate stage for the synthesis of sucrose to take place.

Iodine, silver nitrate, and copper sulphate (M/50,000) each increased the synthetic efficiency a little. Neither iodine nor copper sulphate affected the conversion of glucose to fructose significantly, but the effect of silver nitrate in depressing the conversion of glucose to fructose may have been significant.

Since iodine, silver nitrate, and copper sulphate, all in M/50,000 concentration, are known to inhibit the breakdown of fructose diphosphate by zymohexase, it would appear that inhibiting the action of zymohexase aids the synthesis of sucrose.

Because inhibiting the formation of fructose diphosphate inhibits synthesis, whereas inhibiting the breakdown of fructose diphosphate increases synthesis, fructose diphosphate may be a stepping stone necessary for the formation of sucrose from glucose.

Sodium diethyldithiocarbamate ($2x10^{-5}$ M) had little if any effect upon synthesis. Since this chemical is known to inhibit succinic dehydrogenase, this enzyme evidently plays no part in the formation of sucrose from glucose.

Potassium ferricyanide (3.292 gm/1) interfered with the conversion of glucose to fructose and with the synthesis of sucrose.

Thymol (3 gm/1) decreased both the transformation of glucose to fructose and the formation of sucrose.

Sodium chlorate (0.22%) and sodium pentachlorophenate (0.2%) both depressed the conversion of glucose to fructose and the synthesis of sucrose. The effect of sodium pentachlorophenate was worse than the effect of sodium chlorate.

The Primary Index, Its Meaning and Application to Crop Management With Special Reference to Sugar Cane*

By Harry F. Clements and T. Kubota†

The single prime motivating force in the production of crops is atmospheric energy, in the forms of heat and light. Soil factors as well as certain internal plant factors tend to preclude the realization of maximum yields in any given area. Hence it is desirable for a grower to be able to follow some index within the plant which integrates these factors in relation to the available energy. This index is the Primary Index and is the total sugar level of the elongating cane sheaths expressed as per cent of the dry matter. The basis for the selection of this tissue is reported in part one of this paper.

The significance of the fluctuations of the primary index is reported in part two. As the external factors, sunlight and temperature, increase, the primary index rises. As they decrease, the primary index falls. To the internal plant factors, moisture and growth, the primary index is inversely related. As these fall, the primary index rises. In these studies the factors of soil nutrients such as K and P were at such high levels that their influences on the primary index were not discernible. Nitrogen influences the primary index indirectly as it affects the moisture level.

In part three, the use of the primary index in managing field crops is shown for seven crops.

Introduction

In 1940 the senior author published data showing the quantitative relationship between yield of sugar cane and the available atmospheric energy. In those data there were evident no indications of soil nutrient nor soil moisture deficiencies. The enormous differences in yield observed between the plantings at Waipio and Kailua‡ were traceable to differences in the intensity of sunlight and its absorption at the two locales. "Since differences in atmospheric conditions are so marked, it seems clear that the fertilizer requirement of a crop will differ from area to area and from year to year. Therefore, in order to best integrate the growth of cane with the unpredictable weather, it is necessary to follow some index within the plant which will describe its reaction to the various elements of its surroundings." (3, p. 150.)

Since the publication of that paper, many more data have been compiled, which now may be used to elaborate upon and substantiate the general concept as stated above. In approaching the production of crops from this biodynamic view, the grower is confronted with the realization that the single, prime motivating force in

the growth of plants is the energy available to them from light and heat. Thus the theoretical maximum yield of a given crop in a given area is determined by the energy available to the crop. Once that yield for a given variety is reached, the addition of fertilizers to the soil to increase further the intensity of nutrition is pointless and wasteful.

To achieve these maximum yields requires the complete absence of deterring factors. Such factors may be both internal and external. The internal factors include the restrictions placed upon the whole plant by its conductive systems, leaf structure, root expanse, protoplasmic sensitivity to high energy levels, the variously induced idiosyncrasies of the organism, etc. The external factors which are deterrents to maximum efficiency are moisture insufficient to permit the plant the maintenance of a happy balance with the energy it is receiving, insufficient soil nutrients interfering with the normal integration of the physiological processes operating within it, insufficient soil oxygen and heat interfering with the respiration of the absorbing capacity of the roots thereby interfering with their work of growth, water and nutrient absorption, the presence in the soil of materials toxic to the particular plant, biotic factors such as disease organisms, weeds, rodents, insects, and certainly not the least, man. Whatever the deterring factor may be, the plant reacts to it and as a result its efficiency as a biodynamic organism is interfered with. In many cases when circumstances are less than favorable, the plant undergoes internal reactions which tend toward preserving its life but at the expense of a greatly reduced efficiency (2).

With such myriads of factors, all of them deterrents to the achievement of maximum efficiency, the plight of the grower might be regarded as hopeless were it not for the fact that the plant itself is a sensitive organism and as such reflects its own well-being. Furthermore we may assume a certain spontaneousness on the part of the plant. If external and internal factors are both favorable, we can assume that the plant will grow. Within each species of plants it should be possible to locate a process or index which is sensitive to the balance existing between the external energy and the internal reaction to that energy. As the intensity of the atmospheric energy varies, the plant reacts to it and the new state of balance arrived at should be reflected by the primary index. When such a primary index indicates undesirable trends, the specific secondary indices reveal the cause. In this way the plant itself is informing the grower of its hazards and, when such deterring factors are possible of correction, the grower may come close to realizing maximum returns from the energy available.

Perhaps even more important is the fact that in low-energy areas, where high yields are impossible, relatively high efficiency, however, is possible. The attention of a grower in a low-energy area should not be directed toward the high yields achieved in high-energy areas, but rather toward the efficiency achieved by his own crops under his particular weather and energy conditions. When such a grower sees how much fertilizer and water are used in high-energy areas, he is inclined to use the same quantities. Such practices are not only futile and wasteful, but are frequently injurious to quality, as will be shown presently.

It is fortunate for this type of work that apparently there is no energy area in the Territory which exceeds the growth and assimilation capacity of sugar cane; as a matter of fact, many areas are considerably below such maxima.

Early in these studies it became apparent that the temporary storage of sugars

in such organs as the leaf sheaths was correlated with the balance between photosynthetic production on the one hand and utilization or growth on the other, as related to the environmental condition. Thus as the total sugar level of the sheaths was maintained at about ten per cent (dry weight), there appeared to be a balance between these two contrasting processes. As the sugars dropped below that general level, it was apparent that the growth rate was relatively greater than the rate of photosynthetic production. Such a condition usually obtains during periods of high temperatures, both night and day, especially when associated with conditions of excessive tissue hydration and cloudiness or low light intensity. Obviously under such conditions the sugar content of the cane itself does not keep pace with the addition of new cane. Further, if the growth rate is of such magnitude that it greatly exceeds photosynthetic production, even the permanent reserve which was already laid down is drawn upon for growth. (It should not be presumed that in the life of the plant such conditions are not at times desirable.) It must be appreciated that any deficiency which will directly interfere with photosynthesis will also result in a reduction of the sugar level of the sheaths. Fortunately, however, such cases seem very rare. In culture solution, where iron or magnesium deficiency are induced, resulting in marked chlorosis, even though the growth rate is very low or perhaps even at zero, the sugar level drops very much below the ten per cent level. In the field there appears to be a condition which is sometimes observed in young crops, seemingly brought on either by a combination of inadequate irrigation and inadequately available nitrogen, or by waterlogging, especially on the heavy adobe soils. In a very young crop this combination expresses itself in a very marked yellow-browning of the leaves. As might be expected this chlorosis will impair the photosynthetic efficiency, hence the total sugars of the leaves will drop, even though growth may be at a standstill. However, this condition is so easily detected either superficially or by the moisture and nitrogen indices that it should cause no difficulties.

As the sugar level of the sheaths rises, it is indicative in general of the reverse condition. When conditions are such that the photosynthetic production exceeds utilization of the product, there is an accumulation of sugar in the sheaths. Circumstances bringing about this condition are low temperatures associated with bright weather, low tissue hydration induced either by less than adequate rainfall or irrigation or by very low nitrogen levels within the plant.

Objectives

The objectives of this paper are threefold:

(1) The selection of the most reliable tissue within which the process of temporary sugar storage correlates with the factors of sunlight, temperature, moisture, growth, and such other factors as may affect the biodynamic balance between the plant and its total environment. Thus the level of sugar in that tissue will be the primary index.

(2) The meaning of the variations observed in the primary index.

(3) The application of the primary index in crop management.

Experimental

The general experimental procedure has already been described (4, 5). The data on which this paper is based are a part of the general project on which earlier papers were published.

Carbohydrates were fractionated into reducing sugars, sucrose and hydrolyzable polysaccharides. For the reducing sugars and sucrose, two-gram samples (dry and finely ground) were extracted under reflux with 80 per cent ethyl alcohol for three hours in a water bath. The alcoholic extract is filtered off the residue, and evaporated to near dryness under reduced pressure. The resulting residue is taken up with water, made to volume, cleared with lead acetate and deleaded with disodium phosphate. Aliquots of the cleared solution are taken for inversion with invertase scales. Aliquots of the first solution as well as of the inverted solution are taken for the determination of reducing sugars and total sugars following the method of Quisumbing and Thomas (1, pp. 138–139). Sucrose is determined by difference. In this paper, only the total sugar data are used.

Data and Discussion

Before proceeding toward the realization of the objectives of the paper, it is necessary to list the more important factors which influence the primary index. Since the function of the primary index is to integrate the factors which will describe the balance within the plant in relation to its environment, it is clear that some of these must be external and others internal. The most important external factors are, of course, sunlight and air temperature. Moisture may also be included as an external factor, but here it is treated as an internal factor. As has already been reported, the moisture content of the elongating cane sheaths is a very reliable index to the moisture status of the plant (4), and is itself the result of an integration by the plant and includes many factors such as available moisture, relative humidity, wind, vitality of the roots, etc. Since the primary index supposedly reflects the balance between photosynthetic production and utilization by the plant, then obviously the growth rate must be included. Finally the three most commonly deficient soil elements, nitrogen, potassium, and phosphorus are included. These factors appear to be sufficiently inclusive so that correlations with the primary index are possible. Other factors undoubtedly come to mind. The concentration of chlorophyll is one such. Chlorophyll determinations were not made, but superficially, at least, the chlorophyll concentration is correlated with the total nitrogen and moisture.

Measurements of each of the seven factors mentioned above are obtained as follows:

Sunlight: The intensity and duration of sunlight are measured by obtaining the daily difference between the curves obtained from black-bulb and white-bulb distance soil thermographs. The black bulb is exposed directly to sunlight and the white bulb is placed within a regulation weather kiosk. The difference between the two curves is measured by means of a planimeter and converted to sunlight-degrees by dividing the area so measured by the area of $1°$ F. for twelve hours on the thermograph chart. Admittedly this is a crude measure of light. However, it has shown itself to be useful. The nature of the plant reaction to these values is in the same direction as for gram-calories per cm.^{2} per second as determined by a pyrheliometer, although somewhat weaker. Thus the relationships to be reported later may be regarded as conservative.

Temperature: The daily temperature values are compiled on the basis of weighted average values for a full 24-hour day and are read from the chart of the white-bulb thermograph. The area below the temperature curve is obtained for each 24-hour

period and divided by the area of 1° F. for 24 hours on the chart. In this way a fully weighted average for the entire day is obtained. Both the black-bulb and white-bulb thermographs are checked once each five weeks against a standard mercury thermometer. To accomplish this most reliably, it is necessary to lower both bulbs into a container filled with water. When equilibrium has been reached, the temperature of the water as reflected by the mercury thermometer is used as the standard, and corrections of the thermographs are made when necessary.

Moisture: The moisture content of the elongating cane sheaths (the moisture index) expressed as the per cent of the green weight was used as the measure of the water relations of the plant. Expressing the moisture content on the dry weight of the tissue was found to be wholly undesirable since very large distortions were introduced.

Growth: The growth values for the crops are average elongations expressed as cm. per day. The measurements are made on twenty pilot plants in each plot, the same pilots being maintained throughout the crop cycle. Occasionally a pilot plant is destroyed by rats or accidental breakage and is abandoned. When this occurs early in the crop, a new plant is selected. The natural brown mark on the dorsal side of the topmost sheath bearing a visible dewlap is used as the measuring point.

Nitrogen: The nitrogen index of the plant was used as a measure of the intensity of the nitrogen nutrition. As already reported, this index is the total organic nitrogen content of the elongating cane blades expressed as per cent of the dry matter.

Potassium: The potassium index of the plant is the potassium content of the elongating cane sheaths expressed on the basis of the sugar-free dry weight. The data on which this statement is based will be published shortly.

Phosphorus: The phosphorus index of the plant is the phosphorus content of the elongating cane sheaths expressed on the basis of the sugar-free dry weight. The data on which this statement is based will be published shortly.

Since we are dealing with a rather large complex, it must be apparent at the outset that the task undertaken is no small one. Certainly every one of the plant factors listed above is somewhat dependent on all the other factors, both external and internal. Hence we are not dealing with simple or independent relationships. In one plot the whole course of the crop may be determined by a single factor. In another the course may be determined by another single factor or by a combination of two factors, or three, or four, etc. To proceed by trial and error to discover the situation in each plot leads to tremendous numbers of calculations and, needless to say, defeats. It occurred to us that were we to combine all seven factors at one time and use the method of multiple regression (7), we could determine not only the individual correlations and standard partial regressions of each, but the final multiple regression coefficient (R). From these statistics the relative importance of each factor in each plot might be ascertained. By using these seven factors against the total sugar levels of each of the possible index tissues, we should by the level of R and by the apparent reasonableness of standard partial regressions select the most reliable index tissue and also determine the significance of the primary index as a tool for the guidance of the grower.

The Selection of the Primary Index Tissue:

The primary index tissue has essentially the same requirements as any other index tissue (5), but in addition it should be sensitive to the factors affecting the balance between the physiological processes of the plant as related to the environment in which the plant is growing. The possible tissues meeting all these requirements are the green-leaf sheaths, green-leaf blades, the elongating cane sheaths and the elongating cane blades.

In the earlier phases of this study the first five factors listed above were used. Because of the tremendous number of calculations involved, it was considered most advantageous to select the index tissue at this stage of the study and thus reduce the amount of mathematical work. The R values resulting from the multiple regression were calculated for each of the four possible tissues for each of the sixteen plots and are reported in Table I. Following these calculations, the most important factors in each crop were selected. These were selected as the ones making the greatest contributions to the R values and are reported in Table II.

TABLE I

MULTIPLE CORRELATION COEFFICIENTS[1]

(5 Factors))

	Elongating cane sheaths	Green-leaf cane sheaths	Elongating cane blades	Green-leaf cane blades
Waipio:				
Plot A‡	.8696†	.8667†	.6722	.8340*
B	.8835†	.9175†	.8237*	.9102†
C	.9045†	.7854	.7590	.8403*
D	.7519*	.8382†	.7484*	.7685*
RA	.8869†	.8692†	.8653†	.8233†
RB	.7289*	.8555†	.6973	.6469
RC	.6637	.6609	.6280	.7181
RD	.4921	.8056*	.6806	.6432
Kailua:				
Plot A	.7424	.6866	.6231	.4489
B	.9002†	.9229†	.7302	.8902†
C	.8009*	.8487†	.7773*	.7500*
D	.9189†	.8891†	.8318†	.9181†
RA	.7124	.8286†	.7336*	.8906†
RB	.7721†	.8269†	.8599†	.7809†
RC	.8027†	.7495*	.6580	.6394
RD	.5709	.5944	.7648*	.5779

[1] No mark indicates no statistical significance.

* Indicates statistical significance between the 5 and 1 per cent levels.

† Indicates statistical significance beyond the 1 per cent level.

‡ Plots A, B, C and D at each place are plant crops and differ from each other in the time of planting. Plot A was planted July 28, 1938. The others followed at intervals of three months. Plots RA, RB, etc., are the ratoon crops following the corresponding plant crops.

TABLE II

MULTIPLE CORRELATION COEFFICIENTS
(Most Pertinent Factors)

	Elongating cane sheaths	Green-leaf cane sheaths	Elongating cane blades	Green-leaf cane blades
Waipio:				
Plot A‡	.8463†	.8588†	.6704	.7453*
B	.8814†	.9170†	.8166†	.9092†
C	.9042†	.7846†	.7443*	.8347†
D	.6863*	.7900†	.6716*	.5827
RA	.8563†	.8151†	.8501†	.7588†
RB	.7259†	.8390†	.7097*	.6712*
RC	.6626†	.6497*	.6038*	.6424*
RD	.4855	.7072*	.6657*	.6441*
Kailua:				
Plot A	.7382*	.6526	.5949	.4730
B	.8993†	.9083†	.7238*	.8747†
C	.7939†	.8098†	.7477†	.7108*
D	.9142†	.8480†	.8108†	.8910†
RA	.6786†	.8258†	.7249†	.8458†
RB	.7700†	.8215†	.8587†	.7784†
RC	.7678†	.7105*	.6569*	.6257
RD	.5426	.5929	.7542†	.5081

(*, †, ‡—See explanation in Table I.)

An examination of the significance of the multiple correlation coefficients in Tables I and II shows the rather marked superiority of the sheath tissues over the corresponding blade tissues and we need not concern ourselves further with the latter.

The choice between the elongating cane sheaths and the green-leaf cane tissues is not an easy one to make since both seem to be exceptionally good for the purpose of the primary index. Table I shows a slight superiority for the green-leaf cane sheaths over the other where all five factors are involved in the calculations. Table II, showing the most pertinent factors, shows the two tissues to be of about equal value. These values are, of course, quantitative, but when the qualitative aspect of each multiple correlation is examined, it is apparent at once that the green-leaf cane sheaths are considerably more sensitive to the moisture, often to the near exclusion of the other factors.

Such a situation is not desirable in an index which should tend toward equating all the factors in the plant's environment. The leaf blades are similarly overly sensitive to the moisture level. Such sensitivity is indeed curious, for the moisture level used in this study is that of the elongating cane sheaths. It will be remembered that the moisture levels of the green-leaf cane sheaths and the green-leaf cane blades were markedly inferior to those of the elongating cane sheaths as the moisture index (4). Yet the total sugars of the old sheaths and blades are more nearly related to the moisture index than is the tissue on which the moisture index is based. Probably the explanation is to be sought in the commonly observed fact that older leaves of plants are marginal in the moisture sphere of the plant, and hence it is there that processes are most affected by the moisture level of the plant. At any rate it seems reasonable that such tissues are less desirable as a primary index tissue than are tissues which, although as reliable, give less weight to a single factor. It is clear, of

course, that such factors as sunlight, growth, nitrogen and temperature are all perti-
nent to the energy equilibrium which is sought in the total sugar level. For these
reasons the total sugar level of the elongating cane sheaths remains, at least for the
present, as that best suited to integrate the factors of the environment in relation to
the plant, and is therefore selected as the primary index.

The Meaning of the Primary Index:

Before using the primary index in managing a crop, it is necessary to be aware
of the meaning of the variations within it. At the present stage it is not possible to
give a complete picture of its equating capacities since not all the possible environ-
mental circumstances have been encountered during the past four years in the six-
teen crops which were grown. However, the influences of sunlight, temperature,
growth and moisture seem clearly established. An important start has been made to-
ward an understanding of the influences of the nitrogen, phosphorus and potassium
levels upon the behavior of the plant. The problems of the influences of low calcium
and magnesium as well as high calcium, magnesium and sodium are only now being
undertaken.

In this section it is necessary to rely almost wholly on the statistical method of
multiple regression (7). Using this method three statistics are derived, one, the sim-
ple correlation between each of the seven factors and the total sugars of the elongat-
ing cane sheaths, and two, the standard partial regression between each of the seven
factors and the total sugars of the elongating cane sheaths. (The latter may be de-
fined as the measure of regression between one factor and the total sugar when the
variations of the other six factors [in this case] are neutralized.) Third, from these
values, the multiple correlation coefficients (R) reported in Tables III and IV are
obtained from the following formula:

$$R^2 = (r_{y1}) (\beta_{y0.123456}) + \quad \ldots \quad \ldots \quad \ldots \quad + (r_{y6}) (\beta_{y6.012345})$$

Subscript 0 refers to the phosphorus index of the plant and is the P content of
the elongating cane sheaths expressed as per cent of sugar-free dry weight.

Subscript 1 refers to the potassium index of the plant and is the K content of the
elongating cane sheaths expressed as per cent of the sugar-free dry weight.

Subscript 2 refers to the sunlight record expressed as sunlight-degrees (see text
for complete description).

Subscript 3 refers to the growth rate of the crop expressed as centimeters per day.

Subscript 4 refers to the nitrogen index of the plant and is the total nitrogen con-
tent of the elongating cane blades expressed as per cent of the dry weight.

Subscript 5 refers to the daily air temperature expressed as weighted averages
per day in Fahrenheit degrees.

Subscript 6 refers to the moisture index and is the moisture content of the elon-
gating cane sheaths expressed as per cent of the green weight.

y, in this case, of course, is the total sugar content of the elongating cane sheaths
expressed as per cent of the sugar-free dry weight.

r is the simple correlation coefficient. β is the symbol of the standard partial re-
gression coefficient and R the symbol of the multiple correlation coefficient.

Thus, r_{y0}, r_{y1}, r_{y2}, etc., are the simple correlations between the total sugar con-

tent and the phosphorus index, the potassium index, the light intensity, respectively, etc.

$\beta_{y0.123456}$ is the standard partial regression between the total sugar content of the sheaths and the phosphorus index when all other six factors are held constant. $\beta_{y1.023456}$ is the standard partial regression between the total sugar content and the potassium index when the other six factors are constant, etc.

R^2 is the sum of the products of each pair of correlations and partial regressions. R, the multiple correlation coefficient is obtained from R^2.

In Table III the statistical analysis of the seven factors against the primary index is recorded for each of the sixteen plots. Further, the data for the plant crops (A, B, C, D) are combined for each place and similarly treated. Then the ratoon crops (RA, RB, RC and RD) following the plant crops are combined and analyzed. This is done in an effort to determine the outstanding factors influencing crop growth in the two regions. Unfortunately because of rat damage and blossoming, growth data for the ratoon crops at Kailua were not reliable and are not included.

An examination of the data in Table III reveals that some of the values (correlations and partial regressions) are very low. Some of these pairs have opposite signs (+ and —). Some, on the other hand, are high with the same signs. Some pairs are positive, others negative. Clearly some factors contribute much more to the value of R than others. The significance of R is determined by the analysis of variance. As a result, the larger the number of factors used, the greater is the value of R required for significance. This fact together with the obvious reason that we are chiefly concerned here with an understanding of the primary index requires that in each plot the factors of importance be separated from the others. Thus the most pertinent factors are selected for each plot, the partial regressions and multiple correlations recalculated. These are reported in Table IV. The actual values for R are always somewhat smaller than the corresponding values in Table III, but because of the smaller number of factors, the significance is relatively higher.

Before discussing each factor as it is related to the primary index, it may prove helpful to make a casual, over-all survey of Table IV. The columns headed phosphorus, potassium, etc., with the greatest number of blanks indicate least importance relative to the primary index—those with least blank spaces are the most important in being associated with the variations in the primary index. It is apparent that the most important are sunlight, growth, and water. The least important are phosphorus, potassium and nitrogen. It must be cautioned that this will probably be the case only where these elements are sufficiently abundant so as not to be deterring factors. To continue the general summary of Table IV, at Kailua, a cloudy, non-irrigated area, the data show that three factors alone account for most of the variation of the primary index—water being the most general, with sunlight and growth the other two. In no case are the factors of temperature, phosphorus and potassium associated with variations of the primary index and in only one case does nitrogen enter the picture. In other words whatever influences these factors may have played, their final effect on the sugar level of the sheaths was completely masked by water, sunlight and growth. To translate this discussion into field terms, during the periods when the primary index was high, the crop was suffering mostly from drought. In the later summer and fall, after rains came, the index was low because of excessive moisture

TABLE III

CORRELATION, PARTIAL REGRESSION AND MULTIPLE CORRELATION COEFFICIENTS OF SIXTEEN CROPS

	Phosphorus		Potassium		Sunlight		Growth		Nitrogen		Temperature		Water		R
	r_{y0}	$\beta_{y0.123456}$	r_{y1}	$\beta_{y1.023456}$	r_{y2}	$\beta_{y2.013456}$	r_{y3}	$\beta_{y3.012456}$	r_{y4}	$\beta_{y4.012356}$	r_{y5}	$\beta_{y5.012346}$	r_{y6}	$\beta_{y6.012345}$	
Waipio:															
Plot A:	−.6451	−.3513	−.0872	+.4854	+.4343	+.4220	−.4459	.5513	−.7122	−.2729	+.2233	+.6763	−.6739	+.0984	.9458†
B	−.0806	+.0794	−.3162	+.1361	+.3354	+.1684	−.6453	.4061	−.5724	+.1059	+.6231	+.3877	.7765	−.4665	.9040†
C	+.3206	+.3920	−.2490	−.1428	−.2042	+.0911	−.6878	.3161	−.7944	−.4485	+.0564	−.2377	−.8442	−.2523	.9560†
D	+.2382	+.3372	+.0940	−.5594	−.0516	+.1871	−.4304	.9539	−.5552	−.5558	−.0714	−.0291	−.4416	+.0781	.8368*
RA	−.2840	+.1727	−.5822	−.3793	+.4402	+.4548	−.3133	−1.3765	+.1592	−.2480	+.1104	+.8492	−.3427	+.0611	.9147†
RB	−.4776	.0032	−.5401	+.1669	+.4582	+.1563	−.2815	+.2918	−.4217	+.0463	+.3029	+.2398	−.5891	−.9976	.7360
RC	−.3670	+.4283	−.6025	−.4610	+.0224	−.0531	−.4366	−.1078	−.1269	+.3956	+.1774	+.1797	−.6078	−.7565	.7797
RD	.2231	.2028	−.1197	+.1953	−.0144	+.1612	−.3346	−.7069	+.1508	+.1749	−.0133	+.4679	−.1296	−.0038	.5251
Plant Crops	.0631	+.0204	−.1778	−.0428	+.1761	+.2416	−.5244	.7483	−.5843	−.0240	+.2332	+.5163	−.7093	−.1854	.8409†
Ratoon Crops	.3466	+.0408	−.4878	−.3846	+.2343	+.2243	−.3239	−.4783	+.1119	+.1773	+.1558	+.2904	−.4483	−.1092	.6748†
Kailua:															
Plot A	+.2321	+.3469	−.4032	+.1886	+.6531	+.4029	.0017	.0491	−.5372	−.1838	+.2395	+.0193	−.5773	.4180	.7848
B	−.1420	−.3384	−.2882	+.2366	+.5876	+.2603	.6128	.6213	−.5814	−.0108	+.3303	−.0371	−.7645	.4949	.9412†
C	+.0769	+.3090	−.0824	+.2155	+.4629	+.2168	.5103	.3166	−.3711	+.2238	+.1007	+.0771	−.6740	.8579	.8781*
D	.2614	+.1464	−.1993	+.0576	+.5602	+.2943	−.3813	−.2430	−.5206	−.0718	+.2772	+.1165	−.8167	.7408	.9338†
RA	−.4083	−.0531	−.2040	+.4427	+.3833	+.2333	−.4090	+.0582	−.0900	+.4444	−.1124	−.0631	−.5530	1.2326	.8065
RB	−.3126	+.1435	−.5407	+.4153	+.5207	+.4790			.4713	−.3115	−.1353	−.1010	−.6519	.7373	.7881*
RC	.1753	+.3817	−.3556	+.2981	+.4937	+.4475			−.1871	+.2573	+.0351	−.3550	−.4801	.7373	.7392
RD	.0258	.2105	.1421	−.2069	−.5349	+.5008			+.0383	+.4548	+.0664	−.0355	−.1470	.2482	.5952
Plant Crops	.0691	+.1792	−.1896	+.1453	+.5352	+.2337	−.4105	−.3246	−.4842	−.0003	+.2291	+.0888	−.7324	.6793	.8581†
Ratoon Crops	−.2706	−.0843	−.3477	+.1239	+.4552	+.4719			−.2236	+.1711	−.0384	−.1902	−.4862	.5644	.6647†

(*, †, ‡—See explanation in Table I.)

and growth and cloudy weather. The phosphorus and potassium levels were such that at no time were they associated with the variations of the primary index.

At Waipio where there is abundant atmospheric energy and where irrigation is practiced, the most important factor by far is growth, followed by temperature, sunlight, water, potassium, nitrogen and phosphorus. The nitrogen and phosphorus levels are associated with the variations of the primary index only in the plant crops. Potassium accounts for a fairly large part of the variations in the ratoon crops.

It may be profitable now to describe the influences of each factor upon the primary index somewhat in the order of importance.

Growth: In every case both the simple correlation and partial regression coefficients are negative. The reader, of course, would anticipate this relationship. As the growth rate speeds up, more and more carbohydrate is used up and hence the temporary reserves such as the total sugars of the sheaths (the primary index) will decline. Other things being equal when the growth rate declines, the reserves will rise. This relationship is one of cause and effect, as any grower well knows.

At Waipio in both the combined plant and the ratoon crops, growth is the single most important factor in accounting for the variability of the primary index. The combined plant crops at Kailua, however, show that growth was the least important of the three factors, the most important being water. These relationships signify that at Waipio, the crops, on the whole, were nearer maximum efficiency than were those at Kailua where water was an important deterring factor.

Water: In all cases the simple correlation and partial regression coefficients are negative. When the moisture level of the plant is high, the processes within the plant requiring carbohydrates may proceed until interfered with by other factors. Furthermore when the moisture level is high, the maximum levels of nutrients which the soil can provide are achieved. There is a very high positive correlation between water and nitrogen, potassium, and phosphorus, respectively. So strong are these relationships that one is forced to wonder at the reliability of results obtained in fertilizer trials when the water level of the crop is not controlled. Another aspect of these water-nitrogen relationships is seen when soil water is abundantly available—if the nitrogen levels of the plant and soil are near minimum, the moisture level of the plant remains low until the nitrogen level is raised. This fact is of considerable importance to growers in the high-rainfall areas who generally cannot depend on dry weather to mature their crop. Were these growers to reduce the nitrogen application to levels somewhat lower than needed by the crop, they could dry out their crops, at least throughout a large part of the year—even during wet weather! (See Kailua ratoon crop logs in next section.)

In Table IV the moisture levels of the Waipio crops (irrigated) were less frequently unfavorable than at Kailua. Only in Plots B and C and RB and RC does moisture account for some of the variations in the primary index. Undoubtedly this is so because the crops were thoroughly dried out in summer, prior to harvest. At Kailua, however, where irrigation was not available, water had a much more general effect on the primary index. Recurring droughts, especially during the plant crops, caused unseasonal rises in the primary index.

Thus because of the important role played by water in the life of the plant, both as to its own internal processes as well as its ability to obtain soil nutrients, it is apparent that whenever the primary index is high, the first possible cause to examine

TABLE IV

MOST PERTINENT CORRELATION, PARTIAL REGRESSION AND MULTIPLE CORRELATION COEFFICIENTS FOR SIXTEEN CROPS

	Phosphorus		Potassium		Sunlight		Growth		Nitrogen		Temperature		Water		R
	r_{y0}	$\beta_{y0.\S}$	r_{y1}	$\beta_{y1.\S}$	r_{y2}	$\beta_{y2.\S}$	r_{y3}	$\beta_{y3.\S}$	r_{y4}	$\beta_{y4.\S}$	r_{y5}	$\beta_{y5.\S}$	r_{y6}	$\beta_{y6.\S}$	
Waipio:															
Plot A†	−.6451	−.4092			+.4343	+.1070	−.4459	− .5154	−.7122	−.2287	+.2233	+.5101	−.7765	− .1417	.9034†
B					+.3354	+.2073	−.6453	− .5304			+.6231	+.4346	−.8442	− .3661	.8903†
C	+.3206	+.2632					−.6818	− .3520	−.3041	−.3041					.9354†
D	+.2382	+.3427	+.0949	−.6480			−.4304	− .8949	−.4775						.8187†
RA			−.5822	−.3529	+.4402	+.4466	−.3133	−1.1140			+.1104	+.6378			.9064†
RB					+.4582	+.1792					+.3029	+.3163	−.5891	− .6061	.7314†
RC			−.6023	−.3535									−.6078	− .3703	.7062†
RD							−.3346	− .6122			−.0133	+.4056			.4466
Plant Crops					+.1761	+.2530	−.5244	− .7488			+.2382	+.5368	−.2012	− .2012	.8398†
Ratoon Crops			−.4878	− .3318			−.3239	− .5464			+.1658	+.4572			.6306†
Kailua:															
Plot A					+.6531	+.4938	−.6128	− .4887					−.5773	− .3568	.7271*
B					+.5876	+.1285	−.5103	− .4184					−.7645	− .5899	.9249†
C					+.5602	+.3863	−.3803	− .2537					−.6740	− .6111	.7908†
D													−.8167	− .6364	.9126†
RA									−.0900	+.8610			−.5530	−1.2235	.7740†
RB					+.5207	+.3972							−.6519	− .5651	.7584†
RC					+.4937	+.3625							−.4801	− .3404	.5851*
RD					+.5349	+.5249							−.1470	− .0849	.5415
Plant Crops					+.5352	+.3026	−.4105	− .3334					−.7324	− .5273	.8276†
Ratoon Crops					+.4553	+.3890							−.4862	− .4257	.6197†

§ The remainder of the symbol varies with each plot.
(*, †, ‡—See explanation in Table I.)

is the moisture level. If the moisture level is low, soil moisture is the most likely limiting factor. If the soil moisture is adequate, and still the moisture level in the plant is low, then the plant is suffering from a nutrient deficiency (most probably nitrogen) or from inadequate soil aeration and low soil temperature. The last two factors are common causes in adobe soils following prolonged periods of heavy rainfall. Frequently the plants lose their green color and become brownish-yellow. Under such conditions the primary index will become very low and might cause confusion were not the cause so obvious. Another cause of low moisture levels in the plant when soil conditions are favorable are high wind velocities associated with low relative humidities usually occurring during the spring months.

Sunlight: Table IV shows that without exception the correlation and partial regression coefficients between sunlight and the primary index are positive. That is, over the range of light intensities encountered by these crops, the greater the light intensity, the higher is the sugar level, other things being equal. It is common knowledge that beginning in February and sometimes extending well into July, juices are generally good. From July on, however, juices begin to deteriorate. In part this situation is explainable on the basis of sunlight and temperature and in part on the basis of moisture as affected by sunlight and temperature. In general the duration and intensity of sunlight increase from the first of the year until July, after which both decline until near the year's end. Associated with the increasing light intensity in the first half of the year but lagging behind it is the air temperature (6). Thus during this period the plant is building carbohydrates at a rapid rate, but because of the lower temperatures growth is restricted, hence these carbohydrates tend to accumulate. Further, because of the low temperatures, there is a tendency to underestimate the moisture needs of the plant, especially since during these cool, bright days the relative humidity of the air is low. All of these things combine to raise the primary index and also the quality of cane juices.

During the second half of the year, the situation changes strikingly even though gradually. As the intensity and duration of sunlight decrease, air temperatures continue to rise. Here radiant energy is lagging behind heat energy. Nights are warm, days are hot, and the relative humidity is higher in general than in spring. Coupled with this situation is the tendency toward more frequent irrigations resulting in high tissue hydration, rapid growth and, of course, poor juices. During this time of the year, good yields of good quality can only be effected through proper control of nutrient levels (especially nitrogen), and moisture.

The generally higher importance of sunlight at Kailua in relation to the primary index points to the obvious conclusion that the low intensities observed are the reasons for the generally low yields obtained. At Kailua when moisture is available, the primary index is low because the growth made, even though much less than at Waipio, is excessive in relation to the energy available.

Temperature: Within the range of temperatures recorded during these studies, the effect of temperature on the primary index is, with one exception, positive. This observation may be difficult to reconcile with the statement regarding temperature in the last paragraph. The positive correlations and partial regressions simply mean that within the temperature range observed, other things being equal, the higher the temperature the higher the total sugar level. However, the higher the temperature

the higher is the growth rate, and since the growth rate has a larger influence on the primary index, the influence of temperature is usually masked.

Nitrogen: The influence of nitrogen upon the primary index is somewhat more involved. In Table IV, at Waipio, nitrogen was an important factor in three cases, all plant crops. Here its effects are negative. But in these cases the nitrogen applied was excessive. When the nitrogen was applied as needed by the ratoons, it disappears as an important factor. At Kailua the nitrogen applied to the plant crops was also excessive but because of the dominant effect of moisture, nitrogen was of no significance in relation to the primary index. Kailua Plot R.A, however, shows nitrogen to be significant because of its high positive partial regression. Thus although the correlation was very weak and negative, the partial regression was positive and very important. Its importance in this case is complementary to the effect of moisture. This influence will become clearer when the crop log is examined in the next section.

It perhaps may be helpful, however, to indicate some of the general influences of nitrogen observed in these studies. Reference to Table III will show that the simple correlations between nitrogen and the total sugar levels are for the most part negative. Where they are positive, they are usually weak. Six out of eight partial regressions for the plant crops, where the nitrogen applied was excessive, are negative. In the ratoon crops where the nitrogen applied was more nearly that needed, six of the eight partial regressions are positive, the other two negative. To be sure, most of these values are not significant and were it not for the fact that the nitrogen question is so often raised by growers, especially in those regions subject to periodic droughts followed by excessive rainfall, it would not be discussed here.

The probable cause-and-effect relationships here deal with the supply of energy available to the crop and secondly, the availability of moisture in relation to the energy available. In ordinary field terms these relationships may be expressed somewhat as follows: when there are available generous supplies of energy (both radiant and heat coupled with sufficient moisture, the effect of nitrogen is to force growth and, therefore, it tends to have an inverse effect upon the primary index. On the other hand when the supply of energy, particularly heat, is relatively low or when plants are experiencing deficiencies of moisture, the final effect of nitrogen is to be directly related to the primary index. Actually what may superficially appear to be a dual effect is really one effect. Common experience tells us that where nitrogen is limiting, the leaves are less green than where nitrogen is abundant. Other things being equal, abundant nitrogen thus implies greater vigor, higher metabolism, more chlorophyll, more photosynthesis. Hence under conditions of high temperature and moisture, increased nitrogen is correlated with increased growth and respiration. Under these conditions the stimulating effect of nitrogen on the rate of carbohydrate accumulation is not apparent. But a plant high in nitrogen growing under conditions which will restrain growth, more than it will restrain photosynthesis, will show a direct relation between nitrogen content and carbohydrate accumulation.

This effect has been noted by growers in the low-energy areas, and sometime disastrous results obtain. In cold, cloudy areas which have the additional hazard of drought, the thought has developed that by fertilizing a field heavily, greater sugar yields will result. Also, several growers have felt that applying nitrogen during a period of drought will result in increased yields. Table III shows positive evidence

supporting this contention, but as many of these growers know, the risks involved here are tremendous—greater than justify the practice. The effect of this treatment is essentially mild during the drought, but when the drought is broken, especially during periods of high temperature, there is only one result. The flush of moisture through the dry, well-aerated soil carries the nitrogen with it into the plant and once again the more ordinary effect of nitrogen comes into play—very rapid growth, greatly in excess of the radiant energy, and not only is there much absorption of water by the crop because of the excess nitrogen but in addition there is an actual drain upon the stored carbohydrate so painstakingly accumulated during the period of drought. The result of this may be a large tonnage (much of which is pure water) but a poor yield of sugar.

Potassium: The influence of potassium on the primary index is not discernible in these studies, primarily because the levels were generally high. Plot D at Waipio shows a weak positive correlation but a strong negative partial regression. The importance of this was to strengthen the partial regression of nitrogen. However, when the plant crops of Waipio were combined, no such relationship appeared. At no time at Kailua was there any indication that potassium may be a limiting factor. The Waipio ratoon crops show a negative relationship between potassium and the total sugars. There appears to be no correlation between the potassium levels and growth. It is difficult to determine whether the relationships between potassium and total sugars are cause or effect. Other studies dealing with the influences of potassium are under way, however. Since the relationship is negative, it would mean that a deficiency of potassium would show itself in a high primary index and a low potassium index.

Phosphorus: Phosphorus, as a factor affecting the primary index, is not important in these studies. At Kailua where the phosphorus levels were generally lower than at Waipio, it was not associated with the variations of the total sugars. At Waipio it was of no importance in any of the ratoon crops nor in the combined plant or ratoon crops. In Plot A at Waipio it forms an important part but with an inverse influence. Plots C and D at Waipio show it as a direct influence. Special phosphorus studies which are now underway, indicate that the effect of marked phosphorus deficiency is toward a reduction of the sugar level, but the levels of phosphorus in the plants showing this deficiency effect are far below anything observed in the field studies being reported upon.

In summarizing this part of the paper, it may be stated that the primary index reflects in its variations the balance between the external factors of sunlight and temperature and the internal factors of growth and water. As the intensity of the external factors increases, the primary index rises, and as the intensity of the internal factors, growth and water, increases, the primary index drops. Here, then, seems to be a simple guide which the grower may follow in managing his crop. The factors of soil nutrients *when maintained at adequate levels* are apparently of no importance in influencing the primary index. The levels of K are generally higher for the plant crop than for the ratoons. It should be remembered that the plant crops were grown according to plantation methods whereas the management of the ratoon crops was determined by the primary index. As a result there was a reduction in the variations of the primary index of nearly 50 per cent at Waipio and 30 per cent at Kailua.

The Application of the Primary Index to Field Crops:

In this portion of the paper a series of case records will be presented which were compiled as the crops grew. In the plant crops no attempt was made to guide them on the basis of the primary index. These crops were handled according to plantation practices and were used to establish the various indices. As the work of chemical analysis and growth measurements progressed, the apparent sensitivity of the total sugars of sheaths to factors of the environment showed itself. Thorough studies of it convinced us that it, indeed, was the most important index of all. This realization caused a revision in our estimate of the situation. Indices such as moisture, nitrogen, phosphorus, potassium, calcium, etc., became secondary. By this, it is not to be presumed that we consider them of little importance, but rather that the primary index reveals the status of the plant relative to its environment. When the primary index indicates an unfavorable position, the secondary indices are looked to for causes. When the plant crops were harvested and the ratoons begun, we undertook to grow these crops and manage them entirely on the basis of the various indices. Hence, seven field records will be presented and discussed according to Index records and the strategy used in each case. Four Waipio ratoon crops will be presented first, then two Kailua ratoons, and finally one Kailua plant crop.

Waipio Plot RA:

In Fig. I the crop log* for the ratoon crop, Plot RA, is reported. The sunlight is expressed as sunlight-degrees averaged as daily averages for the five-week intervals. Next is the temperature record expressed as the weighted 24-hour average. The nitrogen index is based on the total nitrogen content of the elongating cane blades (per cent dry matter). The curve below it is the moisture index which is the moisture content of the elongating cane sheaths expressed as per cent of the green weight. The arrows below the moisture curve are dates on which irrigation water was applied. For Kailua, rainfall is plotted below the moisture curve. Below this is the potassium index which is the K content of the elongating cane sheaths expressed as per cent of the sugar-free dry weight. The next curve is the phosphorus index which is the P content of the elongating cane sheath expressed as per cent of the sugar-free dry weight. Below this is the primary index, which is the total sugar content of the elongating cane sheaths expressed as per cent of the dry matter. In the lowest section of the figure are the growth rates of the crop reported as the average in centimeters per day for the thirty-five-day interval. At the bottom are the dates on which collections of samples were made. For several of the curves a line labelled "tentative normal" is drawn across the sheet. These lines are thought to be near the levels which are still adequate for maximum crop yields, although minor adjustments will be made as more experience is accumulated. The normal line for nitrogen is based upon the analysis of the whole leaf. The normal for moisture is based on the known growth behavior of the crop. The normal for potassium and phosphorus is based on analysis made of cane crops grown for many years at Waipio from plots which have received no potash or phosphate fertilization, but which have maintained their yields. The normal for the primary index is an approximation resulting from the sixteen crops grown in this study. All of these "normals" should be regarded as

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* The late Hamilton P. Agee suggested the name "crop log" for such field records. The term may be defined as a record of the crop's progress from its beginning to harvest.
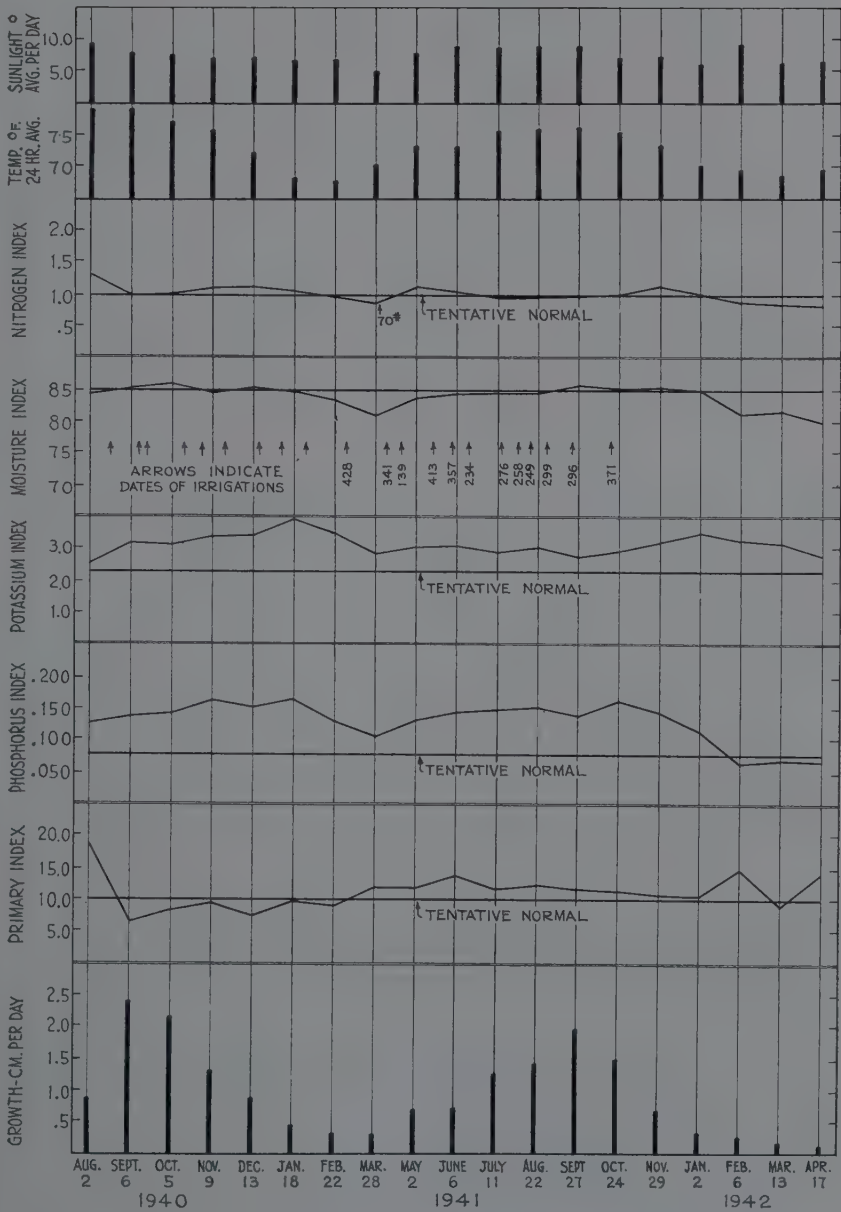
Fig. 1. CROP LOG FOR WAIPIO PLOT RA.

tentative, but at the same time they may be regarded as fairly close to the true normal.

The ratoon crop was begun June 1, 1940. It followed an excellent plant crop which had been well matured. The records for the plant crop showed a high phosphorus index and a moderate potassium index. Therefore, no phosphate was applied to the ratoon. Potash was applied at the rate of 200 pounds of K_2O per acre (muriate). This was done simply as a safety factor, since not enough information had been as yet obtained to omit the potash with confidence. Nitrogen was applied immediately at the rate of 100 pounds of nitrogen per acre as sulphate of ammonia. This seemed like a very heavy application, but later it will be seen that it was not unwise. Five irrigations were applied between June 1 and July 31. Further irrigations are indicated on the field record, as arrows under the moisture index. During the first part of the cycle, irrigations were made more or less by rule of thumb. Beginning in 1941 the Waipio substation placed its irrigation on a day-degree basis. After this the irrigation interval was regulated by the number of day-degrees experienced by the crop since the previous irrigation. The numbers under the irrigation arrows represent the accumulated day-degrees for each interval.

With these explanatory remarks, we may now proceed to follow the crop log as it was compiled.

August 2: The primary index was very high. However, this commonly occurs in the very young plants before they begin rapid growth and if moisture and nitrogen are adequate, it presents no cause for alarm.

September 6: The primary index dropped to a very low level and might be considered dangerous. At that time of the year, with intense heat, that can only mean excessive growth. Actually the growth rate was tremendous, averaging 2.4 cm. per day or nearly $2\frac{1}{2}$ feet per month. But at such an early stage of growth we need to take advantage of the growing conditions and force the crop as much as we can, for there will be several months of less favorable weather soon and during this period the crop can be hardened and prepared for lodging, and so we continue to push it. (Note: Reference to the nitrogen index on September 6, 1940, shows it to be dropping very rapidly. Were we basing our crop management solely on that curve, we would be inclined to apply more nitrogen. However, the primary index is very low indicating that nitrogen is not a deterring factor, hence no nitrogen is applied.)

October 5: The primary index is rising but still is well below the ten per cent line. Moisture is also rising, hence we can lengthen the irrigation interval. Nitrogen is rising. Since no nitrogen was applied, it means that the absorption of nitrogen is continuing at a high rate but since the growth rate is slowing, the nitrogen is at a higher level in the plant.

November 9: Growing conditions are worsening. The primary index is still rising but is approaching normal. Nitrogen continues to rise. Moisture is normal. No change in management is made.

December 13: Cloudy weather is upon us. The primary index drops. Moisture is normal. Nitrogen still rising. No change is made.

January 18: The crop now is in cold weather. Growth for the next two or three months is likely to be very slow. The crop is nicely erect but is becoming tall. We may now take advantage of the cold weather to harden the crop without losing any important growing time. Further, we want the crop in such a position that we can

again force it the coming summer. But if we do not harden it before it lodges, we may have it go down during a storm with resulting losses due to breaking and burying, as experiences in the plant crops had demonstrated. Thus we cut irrigation frequency and impose a drying period upon the crop.

February 22: Evidence that drying is occurring is obtained from the moisture and nitrogen indices. The primary index is still somewhat below normal. We continue the reduced irrigation applying water after 428 day-degrees.

March 28: By this time drying is very pronounced. The primary index has risen above normal. Moisture is low and nitrogen is low. The season is advancing into favorable weather for growth again. Here, then, we reach another period requiring a decision. We can apply more water, but it is also clear that nitrogen will become a limiting factor, hence we make the final application of nitrogen. The quantity to be added must be decided upon. The crop so far has received only the original application of 100 pounds. We know the sunlight which the crop has experienced to date. We look ahead and make a conservative estimate of the sunlight which the crop is likely to experience. To be doubly certain that the estimate is conservative, the last five months of the crop are not included in the estimate. We reason that if 100 pounds of nitrogen carried the crop through the energy available to date, then x pounds should carry us through the forecasted amount. In this case the answer was 70 pounds. The 70 pounds of nitrogen were applied with water on the day indicated by the arrow under the nitrogen curve.

May 2: The primary index has stopped rising. Moisture and nitrogen have risen sharply. No change in program.

June 6: The primary index has risen sharply! Nitrogen is normal. Moisture is somewhat below normal. The crop is going down very satisfactorily but the primary index is too high. We change the irrigation program to a 250-day-degree interval.

July 11: The primary index is better this time. No change in program.

August 22: The primary index is a little high, but not seriously for the second year. With the rising temperatures looming ahead, there is a danger that the second boom stage may cause a lowering of sugar. To be on the safe side, we add 50 day-degrees to the irrigation interval. This is done with caution because the crop is now at a critical point. If its growth during the next two months is excessive, the quality ratio will suffer. If the growth rate is checked severely during the immediate period, there is danger of blossoming. Hence, only a mild lengthening of the irrigation period is effected.

September 27: The primary index is starting downward. Danger of floral initiation is pretty well passed by now for 31–1389. The moisture index is above normal. Growth is heavy. The irrigation interval is lengthened to 375 day-degrees.

October 24: The primary index continues downward! The moisture index is still high. We have our tonnage by now. The harvesting schedule calls for the harvesting of this crop early in April. The falling primary index may become serious, hence something drastic needs be done. The last irrigation was applied on October 13. Harvest is six months away with very uncertain weather between now and then. We decide to stop irrigations at once. If, after a month or two, the moisture index begins to drop sharply, we can always apply another irrigation.

November 29: The primary index continues downward. The moisture index is high. The nitrogen index has risen sharply. No change in program.

January 2: Still the primary index declines. Moisture has dropped a little but is still normal. (Here after nearly three months without irrigations and only minor showers, the moisture index is normal—certainly a saving.) But now harvesting is only three months away.

February 6: At last the primary index has risen sharply, maturation is underway. Moisture has dropped sharply, nitrogen is also dropping.

March 13: The primary index is down again. Moisture has risen only slightly. Nitrogen is down. Certainly there is nothing in these curves to indicate the behavior of the primary index. When the weather records are consulted, the reasons are clear —low temperatures, cloudy weather and showers. The primary index need not frighten us, however, since with both moisture and nitrogen down, a little good weather is all that is needed.

April 17: The primary index is well up, moisture is very low and nitrogen is low. We could extend the crop for another month, but it is practically ready for harvest now. It is harvested and yields 110.4 tons of cane to the acre. The quality ratio is 7.3. The sugar yield is 15.1 tons per acre.*

Summary: During the first part of the crop cycle, the primary index was kept low by extremely heavy growth and high temperature. During the middle part, the primary index was in general high due to sunlight intensity and small growth. In the very last of the crop, moisture and sunlight and temperature were chiefly responsible for the primary index. These observations are verified by the correlations and partial regressions for the plot shown in Tables III and IV. In producing this crop, twenty-six rounds of irrigation, 170 pounds of nitrogen and 200 pounds of potash were used. The potash probably was unnecessary since the potassium index was considerably above the tentative normal. The phosphorus index was also very high. Had another ratoon crop followed the present crop, there would have been no need for phosphorus or potassium fertilization. To reassure those who might question this statement, it may be pointed out that the phosphorus curve was much higher than that of the preceding plant crop despite the fact that no phosphate fertilizer was applied to the ratoon. So far as potassium is concerned, the curve is also considerably above normal, although in this case 200 pounds of potash were applied. Now were another ratoon being started, since the potassium level is known to be high, the new crop might be started without potash application. After the crop is underway for a while, an application can still be made should the potassium index indicate the necessity. However, with the level as high as it was, the chances for a need developing in the next crop are very small.

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Fig. 2. CROP LOG FOR WAIPIO PLOT RB.

Waipio Plot RB:

Plot RB (Fig. 2) was begun August 28, 1940, following the harvest of the plant crop. The plant crop had suffered a good deal from breakage and also from rat damage, but what was there at harvest had been well matured. The phosphorus index of the plant crop had been high, hence no phosphate was applied to the ratoon crop. As in RA, the potassium index was moderately high and until more specific information was available, we decided against taking the risk of leaving it off. Two hundred pounds of potash as muriate of potash are applied together with one hundred pounds of nitrogen as sulphate of ammonia. Again, this application of nitrogen may seem excessive, but later events showed it to be wise. The soil is warm at this season, the stools coming from the plant crop had a good supply of carbohydrate material, and with two to three months of hot weather ahead, the crop can be forced vigorously. There is evidence in these crops that making a heavy initial application under such conditions contributes to the rapid establishment of a dense stand of ratoon shoots.

October 5: Growth was rapid after only five weeks from the plant crop harvest. The primary index is normal, moisture and nitrogen are very high. No change in management.

November 9: The primary index is up, moisture is still very high and nitrogen is dropping. Growth is heavy. No change in management.

December 20: All indices normal or slightly above. (It is interesting to note the very heavy growth that was made so late in the year, somewhat more than two feet since November 9. If we can get such growth by forcing the very young crop as it enters winter, it is that much gained.)

January 18: All indices normal, growth is sharply reduced, but still very good for the season.

February 22: Primary index is dropping, but so early in the cycle, this is not alarming. Moisture is dropping, but despite a light irrigation program, it is still normal. We could shorten the interval between irrigations, but there isn't much to lose at this season of the year. Besides, hardening is taking place.

March 28: The primary index is up. Moisture has dropped sharply and the nitrogen curve is continuing downward. Hardening continues. The crop is in excellent shape and still in very good color, although we could risk the crop going down now, we decide to let it go for another period.

May 2: The primary index is still above normal. Moisture is still low and nitrogen continuous downward. More frequent irrigations are decided upon, but because of some difficulty with water, only one irrigation was made before the end of the period.

June 6: The primary index is above normal. Moisture is actually lower than on May 2. Nitrogen is still dropping. Now we are being confronted with a serious situation. Because of the fact that irrigations were not satisfactory, we cannot be certain that nitrogen is really becoming limiting. If we apply nitrogen without knowing that the plant has exhausted its supply, we are likely to add excessive amounts. Hence, we delay applying nitrogen but we hasten irrigations.

July 11: The primary index is about the same, moisture is rising satisfactorily, but the nitrogen index is still dropping. Hence we can now be reasonably certain

that the crop has used up most of the original 100 pounds. With warm weather upon us, we determine the amount of nitrogen to add on the basis of the sunlight experienced in relation to the contemplated sunlight. This works out to 80 pounds. The nitrogen is applied in the irrigation water and the irrigation interval is shortened to 200 day-degrees.

August 16: Moisture and nitrogen have both risen sharply but so has the primary index. (Here we note that immediately after raising the nitrogen level of the plant, photosynthetic production is stimulated more rapidly than growth.) With moisture above normal, we decide to lengthen the irrigation interval by 50 day-degrees. (Caution: this lengthening process must not be severe, for blossoming might be induced.)

September 20: The primary index is down but is still above normal. Moisture and nitrogen are both high. Hence we extend the irrigation interval another 50 day-degrees, to 300. (It may be noted that the hardening period in spring had been very successful. The cane in lodging had gone down uniformly with no dead cane apparent and with no tendency for the tops to be bunched in large piles, leaving "holes" in the field. There is no evidence of suckering.)

October 24: The primary index is below normal, but there is no need for alarm. The crop is to be harvested about July 1 and hence with a well-hardened crop, we may as well add as many tons as possible at this stage. Moisture and nitrogen are both normal. No change in management.

November 29: The primary index is still dropping. Moisture and nitrogen have risen. We may as well save in costs by lengthening the irrigation interval to 350 day-degrees.

January 2: The primary index is below normal, moisture and nitrogen have dropped. No change in management.

February 6: The primary index is still slightly below normal. No change in management.

March 13: The primary index is down (due largely to very cold, cloudy weather). However, we need not be alarmed for we know that May and June are good maturing months, but to be on the safe side, we lengthen the irrigation interval to 375 day-degrees.

April 17: The primary index is rising, but the crop is now about two and a half months from harvest and with the moisture index tending to rise, we stop irrigations altogether.

May 22: The primary index has risen sharply. Moisture and nitrogen are both dropping.

June 26: The primary index is very high, moisture very low. The crop is ready for harvest.

The yield was 115.6 tons of cane with a Q.R. of 7.1, or 16.28 tons of sugar per acre. At harvest the cane was in excellent condition. This appears to have been a very successful crop. Twenty-eight rounds of irrigation, 180 pounds of nitrogen and 200 pounds of potash were applied. The potash probably was unnecessary. Both the phosphorus and potassium indices are well above normal.

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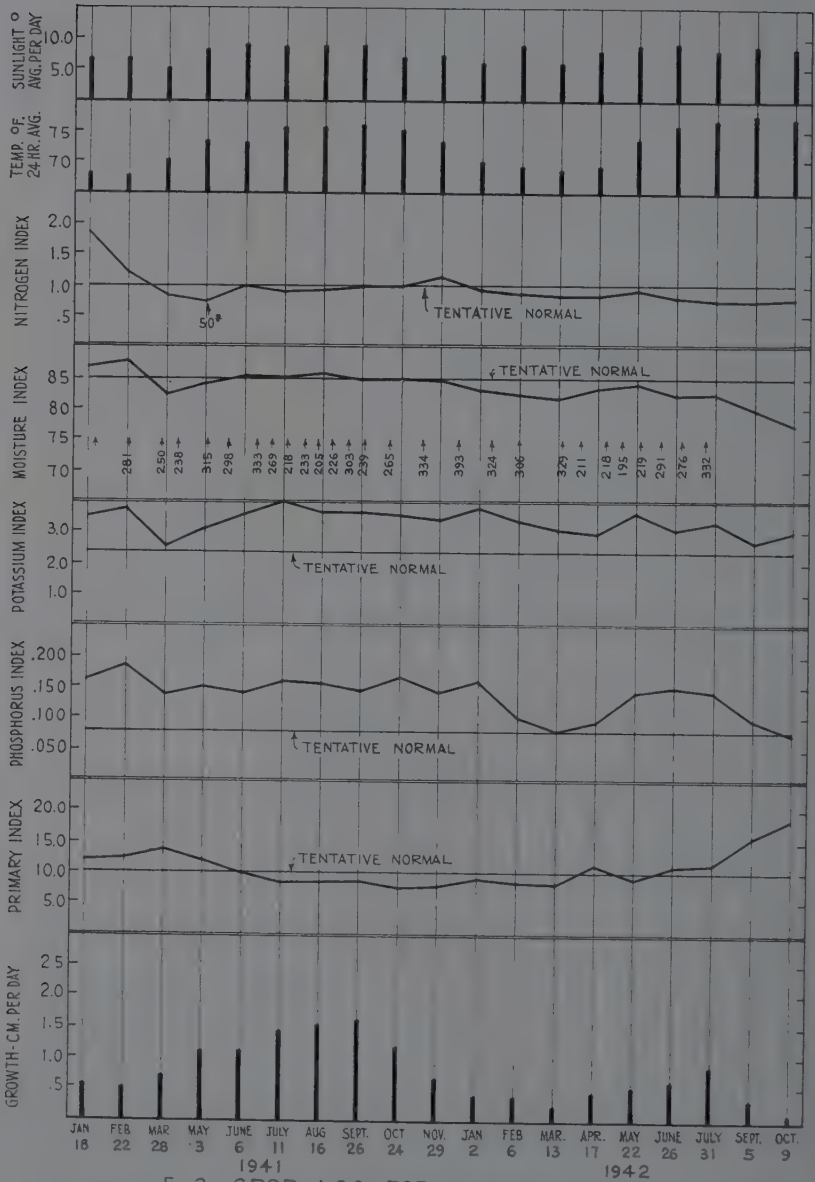
Fig.3. CROP LOG FOR WAIPIO PLOT RC.

Waipio Plot RC:

Waipio Plot RC (Fig. 3) was begun December 1, 1940. The plant crop which preceded it was not a good crop. The yield was 117 tons but the Q.R. was 9.0, yielding 13 tons of sugar. Several reasons can be given for the failure: The crop was badly broken because the mid-crop hardening had not been employed. Rat damage was heavy, and the nitrogen applied was excessive. All of these notes are very important to the fertilizer program of the ratoon, a fact not appreciated until a few months later, and which will be apparent presently. Plot RC was fertilized as were RA and RB—200 pounds of potash and 100 pounds of nitrogen.

January 18: The primary index is high, but both nitrogen and moisture are very high.

February 22: The primary index is rising, moisture is still very high but the nitrogen is dropping very rapidly, a condition usually associated with rapid growth, but the growth is slow. Something is developing here which has not before been encountered.

March 28: The primary index is higher still, moisture is very low for so young a crop and the nitrogen is still dropping. Now, ordinarily this would mean a deficiency of nitrogen since the irrigation interval was being maintained, but only four months before, the crop had received a hundred pounds. What has become of it? In the thought that perhaps something had gone wrong with the irrigation program, a very heavy application of water was made at once.

May 3: The primary index had dropped somewhat, moisture was rising but nitrogen now had reached a critical low. By this time the crop was yellowing badly and obviously something had to be done. The problem still is, what became of the nitrogen that was put on in December? At any rate, the plant was not getting it. To renew the full application would be dangerous, for if the plant finally found the nitrogen previously applied, it would have a great deal too much. So a conservative application of 50 pounds was put on at once.

June 6: The crop has become greener. The primary index is normal. Moisture and nitrogen are again normal. But now other problems confront us. At the rate the crop is now growing, it will begin to lodge in September and October. If we want to harden the crop before it goes down, we shall have to do it before then. At this time the crop is not far enough along to make hardening worthwhile. If we wait until August for hardening, we are likely to set off blossoming. But to help us out of this quandary is the realization that the crop has suffered a good deal and is considerably behind its growth schedule. Possibly even though we push the crop, it may not go down until later, or because it is light, if it did go down, it would not be damaged seriously. So for the time being, we shorten the irrigation interval.

July 11: The primary index is down. Moisture is normal but nitrogen is somewhat low. If it were not for the fact that the original hundred pounds had been put on and very likely was still somewhere in the soil, we would now make a second fifty-pound application. (It would have been much wiser apparently to have used a greatly reduced initial application—especially when the harvested crop had a poor quality ratio and especially during the winter.) But the nitrogen level is not dangerously low. We decide to be conservative and make no further application of nitrogen but we shorten the irrigation interval.

August 16: The primary index is down. Moisture is somewhat above normal, nitrogen is dropping, but the crop is in good color. Growth is fair. We can now begin to lengthen the irrigation interval.

September 26: The primary index remains steady. Moisture is normal and nitrogen is rising. By now it is becoming apparent that the crop is using the nitrogen originally applied.

October 24: The primary index is low, moisture normal, nitrogen steady. The danger of inducing blossoming is now past. We can save some water and at the same time harden the crop which by now is lodged, but there has been damage. The irrigation interval is lengthened.

November 29: The primary index has risen slightly, moisture is normal, but nitrogen has risen. This rise is the result of continued absorption by the roots associated with reduced growth at this late season. That original poundage of nitrogen has not escaped and is being used by the crop. The crop is now about a year old. If we are to add more nitrogen it will have to be done soon. But there are several considerations which have to be weighed. In the first place, the nitrogen level is higher now than it has been since February 22. Secondly, because of the difficulties which obtained early in the cycle, the crop is only fair. Thirdly, to round out a difficult complex, the crop is to be harvested next October—a period which is difficult for maturing a crop. If we apply nitrogen, we may increase the tonnage, but the likelihood of having very poor quality is greatly enhanced. If we are to have a well-matured crop, so that the next ratoon will have a better chance of success than the present crop, all signs tell us not to apply nitrogen at all. So far a total of 150 pounds has been applied. At any rate we can wait another month before finally deciding.

January 2: The primary index has risen slightly, both moisture and nitrogen have dropped. This month is about our last chance to apply nitrogen. We decide against it for these reasons: the drop in moisture is caused by the long irrigation interval, but even so the primary index is low, the color of the crop is good, hence the crop is making sugar, and time is not being lost. Also, the next few months are not good growing months. If we applied nitrogen now it would be there to plague us at harvest time.

February 6: The primary index is again dropping, moisture and nitrogen are also dropping. We could shorten the interval between irrigations but with the low temperatures and low light intensity we can continue with the same schedule, save a little on costs, and not lose much in the way of growth.

March 13: The primary index is still dropping, moisture and nitrogen are getting dangerously low. The crop is beginning to suffer, so the irrigation interval is drastically reduced, from 325 day-degrees to 200. This increased moisture should reverse the trends in both nitrogen and moisture and enable the crop to add a few tons to its growth.

April 17: The primary index has risen sharply. Moisture and nitrogen are both rising. The rise in the primary index again shows the stimulation of photosynthetic activity before growth activity.

May 22: The primary index is below normal again, moisture and nitrogen are returning nearly to normal. Because the primary index has dropped, we lengthen the irrigation to 275 day-degrees.

June 26: The primary index is up now. Harvest is about three months away. At this season, drying conditions are becoming excellent. Should we cut irrigation? If we do, the crop being very low in nitrogen, will dry out too rapidly. Hence we lengthen the irrigation interval to 325 day-degrees.

July 31: The primary index has risen only slightly. Moisture is moderately low and nitrogen very low. Harvest is two months away. Irrigations are discontinued.

September 5: The primary index has risen sharply. Moisture has dropped, nitrogen has been very low. Actually, had it been possible to harvest the crop now, it was ready for it, but the machinery was not available.

October 9: The primary index has continued to rise, moisture is very low and nitrogen is also very low.

At this time the crop is harvested. To continue with the misfortunes experienced all the way through the cycle, the grab-harvester develops a broken clutch and the burned and cut crop remains in the field three days before it is milled. But despite all these adversities, the crop weighed 89.2 tons and had a quality ratio of 7.3. Thus the yield was 12.2 tons of sugar per acre—a yield not to be compared with the previous two crops, but not to be regarded as a total failure.

Because the crop was so difficult, perhaps it is worthwhile now to enumerate the mistakes that were made, and to suggest general principles of handling.

(1) Although Plots RA and RB used successfully the heavy initial application of nitrogen, Plot RC did not. Two factors suggest themselves as casual: (a) The plant crop preceding RC had a very poor quality ratio (9.0) whereas, RA and RB were preceded by well-matured crops (7.2 and 7.5). This fact suggests that the stools and roots of the first two crops were nearly dormant and adequately supplied with carbohydrates. They were, thus, in a position to respond to the heavy application. Plot RC, however, was preceded by a crop still growing at the time of harvest. The stools and roots had not reached dormancy, and were low in available food, hence the heavy application of nitrogen was an error. (b) Plots RA and RB were begun at a time when the soil temperature was rising, hence the nitrogen applied was readily absorbed. Plot RC, on the other hand, was started on December 1, a time when soil temperatures are dropping. Under these circumstances, appreciated as an afterthought, it would have been much wiser to delay the initial application to a later date, or to have greatly reduced it.

(2) On May 3, 1941 when the nitrogen was very low, and had more of a field area been available, it would have been wise to institute an experiment. One block would have received no nitrogen at that time, another would have received the 50 pounds as applied, and another would have received 100 pounds. By following each of the three blocks, we would have obtained much valuable information, useful in later crops.

(3) A similar crisis occurred on November 29 and Jan. 2 (1941–42). Should we have applied more nitrogen on one of these dates? To answer this question, field blocks could again have been set up to answer the question. However, in this experiment only a small plot was available and hence the more apparent, conservative program was followed.

(4) Although specific data are lacking, it appears that losses which are suffered during the early months of the crop cycle are rather directly reflected in the final
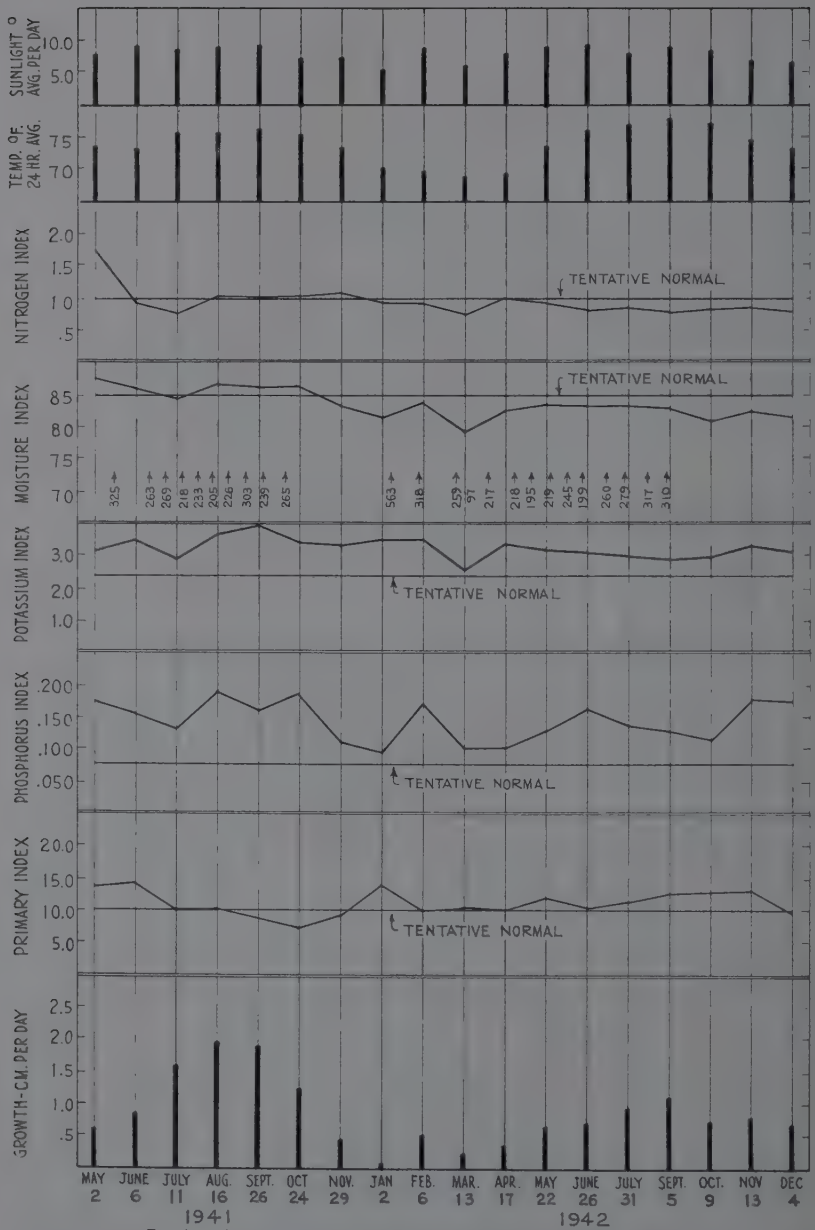
Fig.4. CROP LOG FOR WAIPIO PLOT RD.

crop. It seems likely that attempts during later periods to overcome the initial losses are likely to be defeated by poor quality, resulting from the excess nitrogen.

(5) Finally, a tentative observation may be made for which the crop logs of plots RA, RB, and RC are offered as evidence. If the application of nitrogen to a crop is made when the crop is in a physiological position to absorb all of it or nearly so, the regulation of that crop is simplified enormously over the situation where the nitrogen fertilizer is applied either in great excess or at a time when the absorption capacity of the roots is limited by low temperatures or by paucity of reserve carbohydrates. In the latter instances the fertilizer is distributed through the soil and away from the roots. Although this nitrogen under the conditions of the crops described above was not lost, it was available to the crop at a slow rate, probably only as the roots grew into the soil areas containing the fertilizer. When the fertilizer is applied so that the plant absorbs nearly all of it, the management of the crop is greatly simplified.

Waipio Plot RD:

The crop (Fig. 4) preceding this ratoon was a fair crop, harvested March 3, 1941, with a quality ratio of 7.9. The fertilizers applied at that time were the same as for the previous plots, namely, 100 pounds of nitrogen as sulfate of ammonia, and 200 pounds of potash as muriate of potash. No phosphate was added. Of course, we know now that the heavy application of nitrogen was not wise, but the difficulties experienced with Plot RC were not yet apparent. However, the ratoon of Plot RD followed a better crop than that preceding RC and also we are nearer favorable soil temperatures.

May 2: The primary index is high. Moisture and nitrogen are both high. The nights are cold, but the days are bright and warm.

June 6: The primary index is high, and is rising, moisture and nitrogen are dropping, and the nitrogen curve is doing the same thing it did in RC. We shorten the irrigation interval to 250 day-degrees.

July 11: The primary index has dropped, but moisture and nitrogen are also dropping, the latter to a dangerous low. The young crop is losing color. Exactly the same thing has happened as with RC. This time we won't wait any longer for the summer is upon us. We apply 50 pounds of nitrogen and reduce the irrigation interval to 225 day-degrees.

August 16: Now, the crop has lost its yellow-brown color. The primary index is normal. Moisture is high and nitrogen is normal. No change in management.

September 26: The primary index is below normal, moisture and nitrogen are steady. The irrigation interval is lengthened to reduce costs.

October 24: The primary index is low, moisture and nitrogen are steady. The crop is coming along beautifully. The stand is very heavy and the plants are becoming very tall. We are beyond the danger of inducing blossoming and, to consolidate our gains to date, we undertake to harden the crop during a time when we would not lose much in the way of growth anyway. We stop irrigations.

November 29: The primary index has risen, moisture is down somewhat, nitrogen has risen. The plants are still very erect. Hardening has begun, but has not progressed very far. We continue the hardening program.

January 2: The primary index has risen sharply. Moisture is low. Irrigation is resumed.

February 6: The primary index is normal. Moisture is rising and nitrogen is steady. No change in management.

March 13: Although the primary index is normal, the serious drop in moisture and nitrogen requires attention. This drop was apparently caused by a period of high winds and low humidities extending from about February 10 to March 6, but we have reached the period where the final application of nitrogen has to be made. The situation is complicated by the fact that the temporary drought has lowered the nitrogen level of the plant below what it would be at normal hydration. Hence in making our calculations, we go to the preceding analysis, February 6. Here we note the nitrogen level at 0.93 per cent. If we consider 1.00 per cent as normal and .75 as the absolute bottom of the range we determine the proportion .93 is of this range or 18/25. We calculate the amount of sunlight experienced by the crop, also that contemplated. Since 150 pounds carried the crop through the energy available, and at the same time was within .07 per cent point of normal, then 7/25 of the proportional amount obtained for the anticipated amount should carry the crop the remainder of the cycle. This amount is 30 pounds, which is then applied in the irrigation water. Also, in order to get the crop going as soon as possible, the irrigation interval is shortened to 200 day-degrees. (It should be remembered that the nitrogen applied is conservative because the crop has to be matured in December, not a good time.)

April 17: The primary index is normal. Moisture and nitrogen both have improved. No change in management.

May 22: The primary index has risen but moisture is nearing normal, nitrogen is dropping somewhat.

June 26: The primary index has dropped again. With harvest six months away, we do not want the index to continue this drop, so we lengthen the irrigation interval to 275 day-degrees.

July 31: The primary index is rising, growth is fair. Moisture and nitrogen are below normal. Harvest is 5 months away. No change in management.

September 5: The primary index continues to rise satisfactorily but we are approaching another critical time. With harvest about three and a half months away, weather for maturing the crop is not likely to be very good. Also, the chances of fall rains compel us to start the crop drying. The trend for the primary index during September and October is generally downward, and with the crop so near harvest we must hold the primary index up, unless quality is to suffer. If we can severely check the crop with its low nitrogen level, rains are not likely to affect seriously the quality. We are in danger of setting off blossom, but the drying may be sufficiently intense to prevent that. Hence we discontinue irrigations.

October 9: The primary index has risen very slightly, moisture has dropped, nitrogen has risen slightly. No change in management.

November 13: The primary index is steady, moisture has risen somewhat. Thus, despite the rains (some of them very heavy) since the last part of October, and the warm weather, the crop remains moderately low in moisture. Had excessive nitrogen applications been made, such nitrogen, whether a reserve in the plant or in the soil, would have caused a rapid rise in moisture.

December 4: Rains continued throughout the period. Cloudy weather prevailed. The primary index has dropped but because of the low nitrogen levels, moisture remains low. The crop is harvested. The preharvest burn was poor because of the rains, but despite a 10 per cent weight deduction, the yield was 119.4 tons of cane, the quality ratio, 8.2, and the sugar yield 14.6 tons. The crop received 28 rounds of irrigation, 180 pounds of nitrogen and 200 pounds of K_2O as muriate of potash.

Thus it is apparent that by proper control of crops, it is possible to get reasonably good quality crops even during the worst part of the year. Had nitrogen been applied in excess of the needs of either Plot RC or RD, the tonnage would have been larger (most of the increase being pure water) increasing the cost of harvesting, and the quality would have been poorer. There might even have been less sugar.

CROPS AT KAILUA

The field on which the crops were grown at Kailua is near the base of the mountains. It is in an area of low light intensity, being generally cloudy. Late afternoon shadows from the mountains further reduce the total amount of energy available to the crop. The field is without irrigation facilities. During the crop cycles, there was usually enough rain to maintain growth. Unfortunately, in this area water is likely to be limiting in the late spring and summer, at the time when most growth should be made. When moisture is abundant, during the winter, it is usually too cold for growth. Under such circumstances there isn't much which can be done in managing a crop. But there are some things which had been learned in the plant-crop cycles which were applied. Although the results are far from satisfying, they are presented with the idea that they represent conditions very nearly at their worst and that even under such conditions certain controls are possible. Although the plant crops were fair, in general the ratoon crops, except for RC, started out in an excellent manner. During 1941, however, there was a marked shortage of water, which not only interfered with growth of the crop but seemed to encourage heavy rat invasions. The field used for these studies is completely surrounded by pasture and wasteland and control of the rats under such circumstances was most difficult. All the ratoon crops were very badly damaged. In some cases solid strips of line 10 to 15 feet long had every plant gnawed away. Obviously, under such circumstances the biotic factor is the most important factor in determining final yield.

From a physiological point of view, as well, rats are a serious menace. For example, when a crop has become established and the fertilizer applications are made, it is with the assumption that the whole crop remains on this field. Thus if the crop averages four plants per linear foot, there are about 36,000 upright stalks per acre. Now, if the nitrogen applied to such a field is 100 pounds, it is presumed that the 36,000 plants will be drawing more or less uniformly on this poundage. However, if half the plants are chewed off, or damaged, then there is an excess of the nitrogen for the remaining plants on the field. As the distal portion of the chewed-off stalks begins to disintegrate its nitrogen is leached from it to add to the general excess. Under such conditions we may expect heavy suckering and a serious reduction of quality. Of course the stalks which are partially chewed, even though they continue to grow, will be subject to red rot extending for varying distances up the cane.

When the earlier paper in this series was published, there was some criticism of it on the grounds that the Kailua crops were suffering from phosphorus deficiency.

Even though abundant evidence was offered that such was not the case, yet in deference to the criticism when the ratoon crops were started an especially heavy application of phosphate was applied (400 pounds of P_2O_5) as reverted phosphate. After harvesting the plant crop, a deep furrow was made within one foot of the line of plants, the phosphate applied, and then the furrow was filled in. The object of all this was to place the phosphate where the new roots would reach it. Further, reverted phosphate was used with the idea that the roots would be in the area before all of the phosphate was fixed by the soil. The phosphate index of the plants showed that the phosphate level within the plant was raised considerably, but there is nothing to indicate that the nutrition of the plant was improved by it.

The calcium index of the Kailua-grown plant crops was also at a level very much lower than the corresponding crops at Waipio. Again as an insurance against the possibility that calcium may be limiting, despite much evidence that calcium is never limiting in Hawaiian soils, calcium was applied with nitrogen as calcium nitrate. Again, the levels in the plant were materially raised. The common belief that applying lime to cane reduces its quality could not be verified here. Despite the increase in calcium levels within the plant, quality was decidedly better in the ratoons, but probably not because of the added calcium. If liming causes declining quality, the influencing factor must be other than the calcium composition of the cane. These data will be presented in detail later. Two hundred pounds of potash were applied as muriate.

One final factor needs be presented before proceeding with the crop logs for the Kailua-grown ratoons. In areas where the moisture available to a crop is supplied by rain, there are no means of controlling the supply. However, in this study there have been repeated instances of high correlations between the moisture content of the plant and its nitrogen level. These studies have in many instances shown that where nitrogen is available to the crop, if moisture becomes limiting, the nitrogen content of plant drops. Conversely, where nitrogen is limiting, even though moisture is available, the moisture content of the plant is at a low level. This fact seems to offer considerable hope to those plantations in heavy rainfall areas. If by impressing a physiological drought on the crop, we may obtain reasonably good quality we should not only reduce fertilizer costs, milling costs, but actually produce more sugar. Because of this situation, the nitrogen applied to the ratoons was all applied at once as 100 pounds of nitrogen as calcium nitrate. It is apparent now that it would have been better to break up this quantity, but the logs as presented later do verify the principle of moisture control through nitrogen application.

Kailua Plot RA:

The plant crop was harvested on May 28, 1940. The quality ratio was 9.0. The ratoon crop was immediately fertilized. Response was good despite low rainfall. The stand was dense.

August 3 (Fig. 5) : The primary index is high, nitrogen is moderate for so young a crop, and moisture is very low. But the summer drought seems to be about broken.

September 7: The primary index is now where it should be. Moisture is normal and nitrogen is high considering the growth that is being made.

October 6: The primary index is low, moisture and nitrogen are both high. The crop is doing very well. Evidences of moderate blossoming are apparent.

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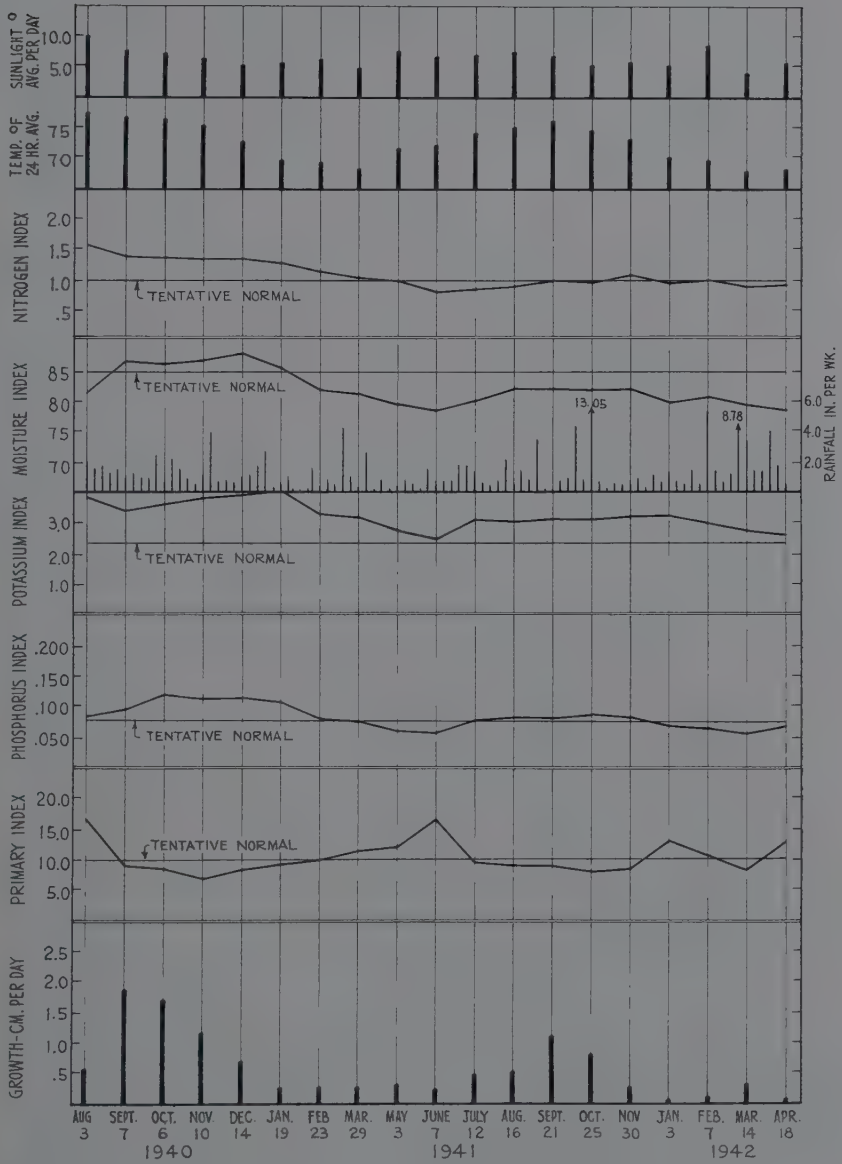
FIG. 5. CROP LOG FOR KAILUA PLOT RA.

November 10: The primary index is very low, moisture and nitrogen are high. Thus, so far we have produced a most promising young crop. Blossoming is moderate and the plants have attained a good height.

December 14: The primary index has risen though it is still low, with moisture and nitrogen still high.

January 19: Primary index is normal, moisture is normal although lower than previously, nitrogen is high.

February 23: Primary index is rising, moisture has begun to drop followed by nitrogen. During this period, there were three successive weeks with only traces of rainfall. Colder weather is also playing a part.

March 29: The primary index is still rising, moisture and nitrogen are both dropping. Despite one good week of rain, the crop is experiencing a shortage of water.

May 3: The same trends continue. Moisture is becoming very low. The plants are now beginning to go down, and many of them, probably because of the dry, hard soil, are breaking off completely and are dying. Rat damage on leaning stalks is becoming very severe, despite rat baiting and poisoning.

June 7: The drought is now extremely severe. The primary index is very high, nitrogen very low, and moisture extremely low. The breakage of plants by lodging and rat damage is a most discouraging sight. What was once such a promising crop, is now a mess.

July 12: Several fair rains, combined with warm weather, have broken the drought. The primary index is normal. Moisture is rising followed slowly by nitrogen.

August 16: Despite barely adequate rains, the primary index has dropped somewhat, moisture has risen and nitrogen, which apparently is not abundant in the soil any more, is rising slowly.

September 21: All indices are steady with a slight rise in nitrogen. But now with excellent temperatures for rapid growth, and seemingly enough rain, the moisture curve remains considerably below normal. In the plant crop where more nitrogen was applied, under similar conditions, there was a very rapid rise in both nitrogen and moisture to points above normal. In this ratoon, however, nitrogen is becoming limiting and is affecting the moisture content of the plant.

October 25: The same situation continues despite abundant rainfall and favorable temperatures.

November 30: Despite a drenching rain, the moisture content remains low.

January 3: Colder weather, somewhat reduced rains, although not a drought, raises the primary index, drops moisture and nitrogen. Harvest is three months away.

February 7: The primary index is down, moisture has risen somewhat but is still low.

March 14: A very cold, cloudy period. The primary index is down, but despite considerable rainfall, the moisture index is lower as is nitrogen.

April 18: Following a period of improved temperature and with abundant soil moisture, moisture is lower than that at Waipio (see Fig. 1). Nitrogen is below normal, though not materially so. The primary index is up.

The crop is harvested and yields 42.9 tons of cane with a quality ratio of 7.39, or

5.81 tons of sugar. Now, to be sure, this is not a satisfying yield, but it does seem clear that even though crops in the high rainfall area are subjected to rains during the maturing period, they can be made to yield satisfactory quality ratios if nitrogen is limiting. If excessive amounts of the element are applied, they will be there in the soil to plague the grower when harvest comes around.

In this case it seems now that it would be wiser to apply about 50 pounds at the start, and then at the beginning of the second season (in this case, about May 3, 1941) apply the calculated amount. In this way we could probably have had a rapid recovery and better growth during the summer. The yield itself was, of course, greatly reduced because of the extensive rat damage. At harvest about 75 per cent of the stalks were chewed or broken. Obviously where rat infestation is heavy, an important part of the cultural practice should revolve about controlling the menace.

Kailua Plot RB:

The crop which was followed by this ratoon was harvested August 27, 1940. Its quality ratio was 9.5. Plot RB was fertilized at once and with abundant warmth and sufficient rain, it started out with a very heavy stand.

October 6 (Fig. 6) : The primary index is low, moisture and nitrogen very high.

November 10: The primary index is still low, although rising, moisture and nitrogen are high.

December 14: Despite colder temperatures, growth is continuing.

January 19: All indices are good.

February 23: Although the rainfall is becoming limiting, this crop at this time has a higher moisture level than RA. (Probably aided by the higher nitrogen level.)

March 29: The primary index is normal, suggesting that the crop is not suffering from the lack of water even though the moisture index is dropping.

May 3: The primary index is now rising, moisture is very low, nitrogen, too, is reflecting the moisture condition.

June 7: The primary index is high, moisture remains low, and nitrogen continues to drop.

July 12: Improved rainfall has lowered the primary index, raised the moisture index. Nitrogen remains steady. (At this point we could have had a speedier recovery of the crop from the drought were we to add some nitrogen. It would have been better to apply less at first and put on a calculated amount at this point.)

August 16: The primary index is normal, moisture is rising slowly, nitrogen is steady.

September 20: The primary index is low, moisture normal and nitrogen nearly so. (In other words there is still enough nitrogen in the soil.) The crop is in excellent condition. It is still erect, very dense, and so far, there has been practically no rat damage, despite the heavy infestation in the adjoining Plot RA. However, the crop (RB) is becoming topheavy and is likely to go down very soon.

October 25: With the very heavy rainstorm, the crop has gone down, but probably because of the hardening induced by the drought, there appears to be very little breakage. The primary index is down, moisture has dropped, as has nitrogen.

November 30: Despite rat baiting and poisoning, rat damage is heavy. The primary index is still low. Nitrogen is normal, moisture is steady.

January 3: The rat damage becomes extremely severe.

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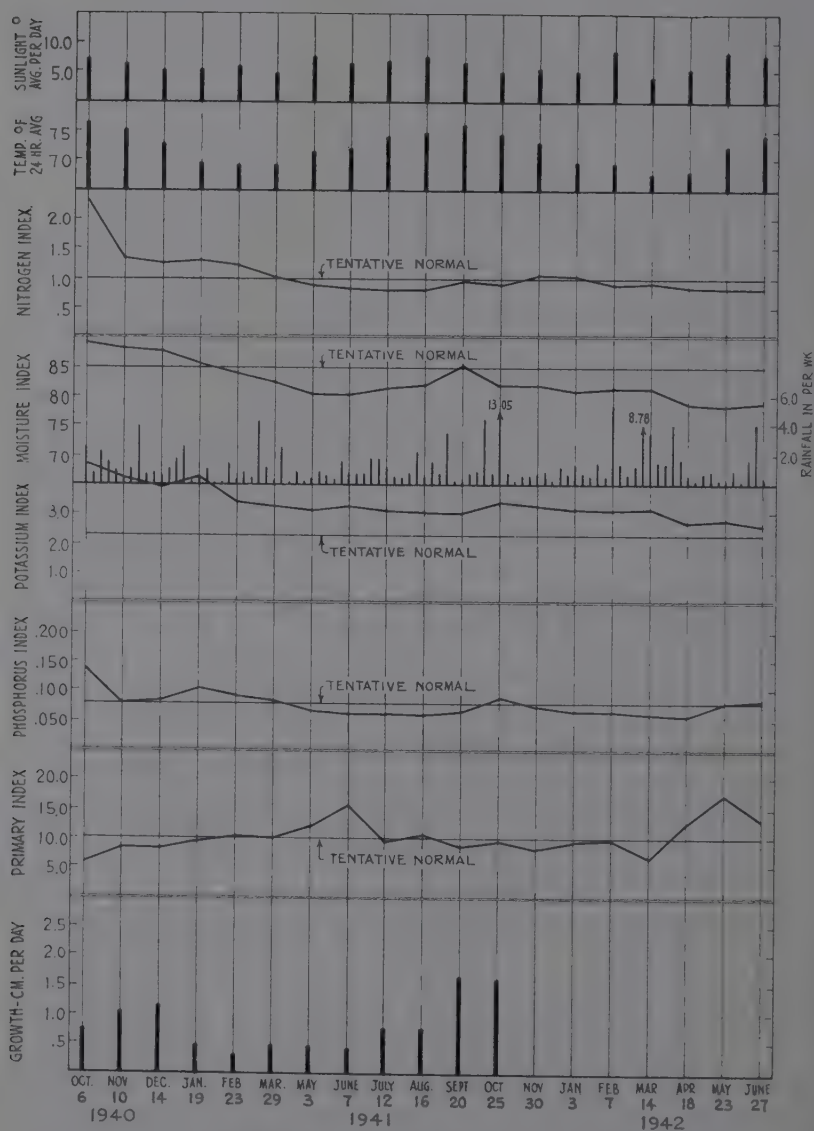
Fig. 6. CROP LOG FOR KAILUA PLOT RB.

February 7: The primary index is normal, moisture continues low and nitrogen is dropping.

March 14: After a very cold, cloudy period the primary index has dropped, even though nitrogen and moisture are both below normal.

April 18: Here we begin to get the real effects of the developing nitrogen deficiency. The primary index is rising and moisture and nitrogen both drop, despite heavy rains.

May 23: The same trends continue.

June 27: With rising temperatures, the primary index drops, but is still high, moisture and nitrogen are both low.

The crop is harvested and yields 55.2 tons of cane with a quality ratio of 6.99, thus yielding 7.9 tons of sugar, a crop which can be regarded as excellent considering the drought, rat damage, etc.

The relation between nitrogen and moisture is an important one. Kailua Plot RA received 52.70 inches of rain during the first eleven months of its growth and 80.58 inches during the second eleven months. Plot RB received 49.00 inches during the first eleven months and 83.35 during the second eleven months. Despite the heavy rains as harvest approached the moisture levels within the crop remained low, due to the reduced nitrogen levels.

In order to give the reader a case for comparison, the crop log for a higher nitrogen field (KC) is reported. This plot was grown without reference to the curves. The application of nitrogen was made on the basis of what was then accepted practices. At planting an application of Ammo-phos was made to give 200 pounds of P_2O_5 and 44 pounds of nitrogen. Further, 200 pounds of K_2O as muriate of potash were also applied. Two further applications of nitrogen as sulphate of ammonia were made, as indicated on the nitrogen index. For the entire cycle, 160 pounds of nitrogen were applied. Rainfall was adequate, except for two short summer periods. During the first eleven months, 76.56 inches of rain fell and during the second eleven months, 73.16 inches. The field was planted January 28, 1939. The 31–1389 planting material was cut at the Waipio substation, and soaked in warm water (35° C.) for about 24 hours prior to planting. Germination was excellent, despite cold weather.

Kailua Plot C:

March 24 (Fig. 7): The primary index is low, moisture and nitrogen are very high.

April 21: The primary index is normal, moisture and nitrogen very high. The crop is growing beautifully and is dark green in color.

May 26: The primary index is dropping somewhat, moisture is normal, nitrogen is high. However, the fertilizer schedule calls for a nitrogen application. Fifty-six pounds of nitrogen as ammonium sulphate are applied. It should be obvious that there was no need for this application. The nitrogen index was well above normal. The primary index is low. Moisture is dropping, but this is due to a lighter rainfall.

June 27: The primary index is dropping, as is moisture. Nitrogen is above normal.

July 23: The primary index is steady, nitrogen is high, moisture continues to drop. The drought is now beginning to check growth.

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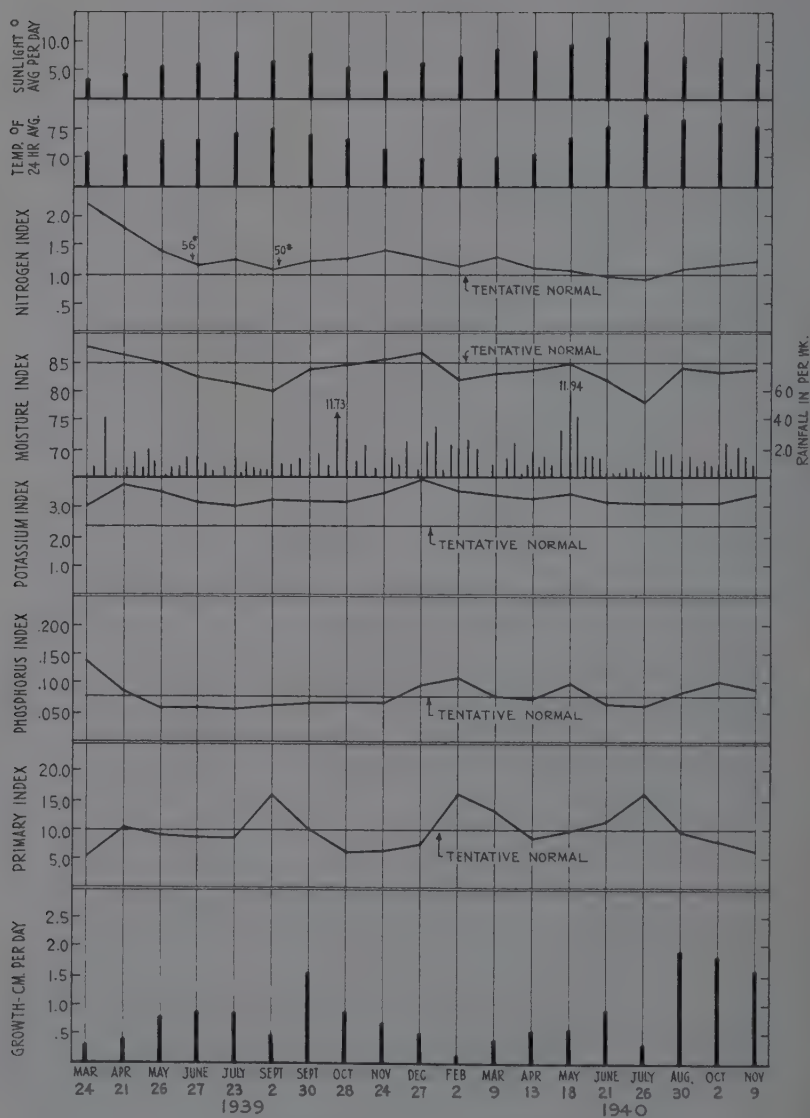
Fig. 7. CROP LOG FOR KAILUA PLOT C.

September 2: The primary index has risen sharply, moisture is low, nitrogen is dropping, but most likely because of the drought. A good four-inch rain fell at this time. The last application of nitrogen was made. (At least one of the two applications of nitrogen was unnecessary.)

September 30: Following the rain, a very rapid recovery was made. Growth is very heavy. The primary index is normal, moisture is nearly normal, nitrogen, despite the heavy growth is rising.

October 28: One very heavy rain and several substantial rains have fallen. The weather is cloudy and hot. The primary index is down. Moisture is normal and nitrogen is very high. (A curious fact asserted itself at this point. Two older plots (6 and 3 months, respectively) and one younger plot (3 months) showed heavy blossoming, but Plot C except for a few blossoms on the edge of the field had no blossoms.)

November 24: The primary index is very low, moisture is high and nitrogen is very high.

December 27: The primary index is low, moisture is high and nitrogen very high.

February 2: Cold weather, and somewhat improved sunshine starts the primary index upward, moisture is down, nitrogen is high.

March 9: The primary index is dropping, moisture and nitrogen are rising.

April 13: All indices are nearly normal.

May 18: All indices are normal. Harvest is about six months away. The crop is dark green and has made excellent growth. There has been very little breakage and practically no rat damage.

June 21: The primary index is rising, moisture is dropping and nitrogen is normal. A drought is beginning.

July 26: The primary index is high, moisture is low and nitrogen is somewhat below normal. Growth was heavily curtailed by the drought. This would be a good time to harvest. However, the schedule calls for harvest about November 1.

August 30: Several good rains, result in a burst of growth. The primary index is down, moisture is nearly normal and nitrogen is rising. With harvest two months away, these curves bode ill.

October 2: The primary index is well below normal, moisture is nearly normal and nitrogen is above normal and is rising with harvest only one month away! Growth is heavy.

November 9: The primary index is very low. Moisture nearly normal and nitrogen very high. The crop is harvested and yields 91 tons of cane with a quality ratio of 12.78 and 7.1 tons of sugar. Compare this yield with KRB, grown under much less favorable circumstances which yielded only 55.2 tons of cane and 7.9 tons of sugar. It should be remembered that rainfall for Plot C was adequate both seasons, whereas rainfall was less than adequate the first season for RA and RB and heavy during the harvest season. To strike a cost comparison between Plot C and RB, 60 per cent more nitrogen was used for Plot C. For each ton of sugar, nearly six additional tons of weight (mostly pure water) had to be harvested and hauled.

The nitrogen curves for Plot KRB and KC may be compared for general levels. The curve for RB was normal or below for the most part after March 29, 1941, while that for C was normal or below on only two occasions, both late in the cycle. The nitrogen index for RB just prior to harvest was below normal and was drop-

ping. That for C was above normal and was rising. It seems very clear that the 160 pounds of nitrogen for Plot C were excessive. Had the additions of nitrogen been made according to the index, at least one of the applications would not have been made. But the excess of nitrogen whether still in the soil or in the plant is really of little moment, since in either case it will be used by the plant when conditions are otherwise favorable. Actually, much of the excess was in the plant. (Cf. nitrogen compositions of cane KC and KRA, pp. 166 and 168, Vol. 46, this journal.)

Two other comparisons may be made. *First:* The potassium index for KC is very high. Had the index been followed at that time, the application made to the ratoon crop would not have been made. *Second:* The phosphorus index for KC was below the tentative normal for the first half of the crop and about normal for the remainder. Even though there is nothing to indicate that phosphate was a deterring factor in growth, a double application of P_2O_5 (400 pounds) was made on the ratoons. During the first half of the ratoon crops (RA and RB) the phosphorus index was normal or above. During that part of the log where moisture was below normal, the phosphorus index dropped. In fact, there appears to be a good correlation between the phosphorus levels of the crop and its moisture content. (KRB, +.6476,** KRA, .9353,**.)

General Discussion

There are two general approaches to the solution of crop problems encountered in the field. One involves the empirical application of various treatments, fertilizers, water, type of planting, etc., upon the crop. Plans are carried out according to schedule and little attention is paid to the crop as it grows. The results of the treatment are determined at harvest time. The second general approach is that reported in this paper. Here certain measurements associated with the welfare of the crop are made at intervals of five weeks. The time of applying fertilizers (except for phosphorus), the quantity of fertilizer, the length of the irrigation intervals, the length of the maturing period, etc., are not worked out before hand but are worked out as the crop progresses, basing the decisions made at any one time on the progress made by the crop as revealed in the crop log. In this way the variations of climate, which are not inconsiderable, are taken into account as the crop progresses. With the establishment of the crop log, a complete record of the crop is available not only for use in guiding the particular crop to its harvest, but serves then as a series of precise measurements which may be used not only for comparison with other fields but over a long series of years with the same field.

The empirical method has a very important place in the crop-log approach. Thus when the time is reached that a decision must be made with reference to a particular practice, for example, the final application of nitrogen in Waipio Plot RC, Fig 3, January 2, 1942, if the grower has not encountered that particular situation before, he can institute a block experiment at that point. The plots are logged and from the subsequent behavior of the curves as well as the final harvest data, he accumulates information which will be useful when similar crises develop in the future.

Summary

1. The elongating cane sheaths are found to be the plant organ within which the total sugar level best serves as the primary index.

2. The primary index is sensitive to variations of sunlight, temperature, growth rate, moisture and perhaps nitrogen, potassium and phosphorus.
    (a) It is positively correlated with sunlight, temperature, and sometimes nitrogen and phosphorus.
    (b) It is negatively correlated with growth, moisture, potassium and sometimes nitrogen and phosphorus.
3. The part which the primary index plays is important. Under conditions where growth is below normal for the particular environment, the index rises. Where growth is excessive, the index drops. Because of this behavior, the index may be used as a guide in fertilization, irrigation, and crop management in general.
4. The crop logs of six ratoon crops (four at Waipio and two at Kailua) and one plant crop (Kailua) are presented in detail showing the use of the primary index and the secondary indices in managing the particular crop while it grows.

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Sugar Prices

96° CENTRIFUGALS FOR THE PERIOD
JUNE 16, 1943, TO SEPTEMBER 15, 1943

Date	Per pound	Per ton	Remarks
June 16, 1943–Sept. 15, 1943.........	3.74¢	$74.80	Philippines

THE HAWAIIAN PLANTERS' RECORD

H. L. LYON, *Editor*

EXPERIMENT STATION STAFF

H. L. LYON, Director

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